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Technology Evaluation Report: SITE (Superfund Innovative Technology Evaluation) Program Demonstration Test International Waste Technologies In situ Stabilization/Solidification Hialeah, Florida, Volume 1

Foster Wheeler Enviresponse, Inc., Edison, NJ

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16. ABSTRACT

A demonstration of the International Waste Technologies (IWT) process, utilizing the Geo-Con, Inc. deep-soil-mixing equipment has been performed under the Superfund Innovative Technology Evaluation (SITE) Program. The demonstration occurred in April 1988 at the site of a General Electric Co. electric service shop in Hialeah, FL where the soil contained polychlorinated biphenyls (PCBs) and localized concentrations of volatile organics and heavy metal contaminants. The demonstrated process mixed the contaminated soil in situ with a mixture of a proprietary additive, called HWT-20, and water.

The technical criteria used to evaluate the effectiveness of the IWT process were contaminant mobility, based on leaching and permeability tests; and the potential integrity of solidified soils, based on measurements of physical and microstructural properties. The performance of the Geo-Con deep-soil-mixing equipment was also evaluated.

The process did appear to immobile PCBs. However, because of very low PCB concentrations in the leachates, caused in part by the low concentrations of PCBs in the untreated and treated soils, absolute confirmation of PCB immobilization in this SITE project was not possible. Physical properties were satisfactory except for the freeze/thaw weathering test, where considerable degradation of the test specimens occurred. The miscrostructural analyses showed the process produced a dense homogeneous mass with low porosity.

The cost per ton of treating contaminated soil under the demonstration test conditions was determined at approximately $194.

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Volume I

SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

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Technology Evaluation Report:
SITE Program Demonstration Test International Waste Technologies In Situ Stabilization/Solidification Hialeah, Florida

Volume I

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Office of Research and Development
U.S. Environmental Protection Agency
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NOTICE

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FOREWORD

The Superfund Innovative Technology Evaluation (SITE) program was authorized in the 1986 Superfund amendments. The program is a joint effort between EPA's Office of Research and Development and Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous- waste treatment technologies necessary to implement new cleanup standards, which require greater reliance on permanent remedies. This is accomplished through technology demonstrations designed to provide engineering and cost data on selected technologies.

This project consists of an analysis of the International Waste Technologies proprietary in situ stabilization/solidification process and represents the sixth field demonstration in the SITE program. The technology demonstration took place at a former electric service shop owned by General Electric Company in Hialeah, Florida. The demonstration effort was directed at obtaining information on the performance and cost of the process for use in assessments at other sites. Documentation will consist of two reports. The Demonstration Test Report describes the field activities and laboratory results and has been previously issued. This Application Analysis Report provides an interpretation of the available data and presents conclusions on the results and potential applicability of the technology.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Building, Springfield, Virginia, 22161, (702) 487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at 1-800-424-9346 or (202) 382-3000 in Washington, D.C. to inquire about the availability of other reports.

ABSTRACT

A demonstration of the International Waste Technologies (IWT) process, utilizing the Geo-Con, Inc. deep- soil-mixing equipment has been performed under the Superfund Innovative Technology Evaluation (SITE) Program. This was the first field demonstration of an in situ stabilization/ solidification process. The demonstration occurred in April 1988 at the site of a General Electric Co. electric service shop in Hialeah, Fla. where the soil contained polychlorinated biphenyls (PCBs) and localized concentrations of volatile organics and heavy metal contaminants. The demonstrated process mixed in situ the contaminated soil with a mixture of a proprietary additive, called HWT-20, and water.

The technical criteria used to evaluate the effectiveness of the IWT process were contaminant mobility, based on leaching and permeability tests; and the potential integrity of solidified soils, based on measurements of physical and microstructural properties. The performance of the Geo-Con deep- soil-mixing equipment was also evaluated.

The process did appear to immobilize PCBs. However, because of very low PCB concentrations in the leachates, caused in part by the low concentrations of PCBs in the untreated and treated soils, absolute confirmation of PCB immobilization in this SITE project was not possible. Physical properties were satisfactory except for the freeze/thaw weathering test, where considerable degradation of the test specimens occurred. The microstructural analyses showed the process produced a dense homogeneous mass with low porosity.

The Geo-Con deep-soil-mixing equipment performed well, with only minor difficulties encountered, which can be easily corrected. The HWT-20 additive was well dispersed into the soil, as evidenced by the relatively uniform change in chemical and physical characteristics of treated soil versus untreated soil.

The cost per ton of treating contaminated soil under the demonstration conditions was determined to be approximately $194.

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ABBREVIATIONS AND SYMBOLS

AA -- atomic absorption - flame or furnace--for metals detection
ANS 16.1 -- Leach test used by the American Nuclear Society
ASTM -- American Society for Testing and Materials
cm/s -- centimeters per second - permeability coefficient units
DSM -- deep soil mixing
EPA -- Environmental Protection Agency
ft -- foot
g -- gram
gal -- gallon
GC/ECD -- gas chromatography/electron capture detector
GC/MS -- gas chromatography/mass spectrometry
gpm -- gallons per minute
GE -- General Electric Co.
h -- hour
HWT-20 -- proprietary additive of International Waste Technologies
IDLH -- immediately dangerous to life or health
IWT -- International Waste Technologies
kg -- kilogram
L -- liter
lb -- pound
MCC-1P -- Leach test developed by the Materials Characterization Center
mg -- milligram
mL -- milliliter
NIOSH -- National Institute for Occupational Safety and Health
O&G -- oil and grease
ORD -- EPA Office of Research and Development
OSWER -- EPA Office of Solid Waste and Emergency Response
PCB -- polychlorinated biphenyl
ppm -- parts per million
psi -- pounds per square inch
rpm -- revolutions per minute
SEM -- scanning electron microscope
SITE -- Superfund Innovative Technology Evaluation
SWS -- Scientific Waste Strategies, Inc.
TCLP -- Toxicity Characteristic Leaching Procedure
TOC -- total organic carbon
μ -- micron
UCS -- unconfined compressive strength
VOC -- volatile organic compound
XRD -- X-ray diffraction

CONVERSIONS

	English (US)	Metric (SI)
Area:	1 ft^2	9.2903×10^{-3} m^2
	1 in^2	6.4516 cm^2
Flow rate:	1 gal/min	6.3090×10^{-5} m^3/s
	1 gal/min	6.3090×10^{-2} L/s
	1 Mgal/d	43.8126 L/s
	1 Mgal/d	3.7854×10^{3} m^3/d
	1 Mgal/d	4.3813×10^{-2} m^3/s
Length:	1 ft	0.3048 m
	1 in	2.54 cm
	1 yd	0.9144 m
Mass:	1 lb	4.5359×10^{2} g
	1 lb	0.4536 kg
Volume:	1 ft^3	28.3168 L
	1 ft^3	2.8317×10^{-2} m^3
	1 gal	3.7854 L
	1 gal	3.7854×10^{-3} m^3

ft = foot, ft^2 = square foot, ft^3 = cubic foot
in = inch, in^2 = square inch
yd = yard
lb = pound
gal = gallon
gal/min = gallons per minute
Mgal/d = million gallons per day
m = meter, m^2 = square meter, m^3 = cubic meter
cm = centimeter, cm^2 = square centimeter
L = liter
g = gram
kg = kilogram

m^3/s = cubic meters per second

L/s = liters/second

m^3/d = cubic meters per day

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SECTION 1

EXECUTIVE SUMMARY

1.1 INTRODUCTION

In response to the Superfund Amendments and Reauthorization Act of 1986 (SARA), the Environmental Protection Agency's Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response (OSWER) have established a formal program to accelerate the development, demonstration, and use of new or innovative technologies as alternatives to current containment systems for hazardous wastes. This program is called Superfund Innovative Technology Evaluation, or SITE.

The major objectives of the SITE Program are to develop reliable cost and performance information. One process, which was demonstrated in April 1988 at a General Electric Co. (GE) electric service shop in Hialeah, Fla., as part of the SITE Program, was the International Waste Technologies (IWT) in situ stabilization/solidification process, using Geo-Con, Inc. deep-soil-mixing equipment. This was the first field demonstration of an in situ stabilization/solidification process. The demonstration was performed to meet the goals of the SITE program along with those of GE, which were significantly different. GE's goals were to meet the requirements of the Metropolitan Dade County Environmental Resources Management (MDCERM) for the immobilization of PCBs. The SITE project proposed to determine the technological and economic viability of the in situ stabilization/solidification process, as defined in the Demonstration Plan, and involved a more expansive testing program than that required of GE by MDCERM.

IWT, the stabilization/solidification technology developer, and Geo-Con, provider of the specialized drilling and mixing equipment, were participants in both the SITE and GE programs. Under the latter program, IWT and Geo-Con served as contractors to GE for the mandated test before the site remediation. In addition, under a cooperative agreement with EPA, IWT was designated as the SITE technology developer for the demonstration test; Geo-Con verbally agreed that its in situ procedures were to be evaluated.

The IWT process involved the in situ mixing of the service shop soil contaminated with polychlorinated biphenyls (PCBs) with a cement-organo clay mix referred to as HWT-20. Two 10 x 20 ft test sectors (designated Sectors B and C), relatively high in PCBs for the site were treated. Sector B was treated to a depth of 18 ft and Sector C to a depth of 14 ft. These depths were defined by GE to treat all the soil containing at least 1.0 mg/kg of PCBs. The developer claimed the wastes would be immobilized and bound into a hardened, leach-resistant, concrete-like solidified mass.

The major objectives of this SITE project were to determine the following:

1. Ability of the stabilization/solidification technology to immobilize PCBs. (If detected in the untreated soil, immobilization of volatile organics and heavy metals were to be measured.)

2. Effectiveness, performance, and reliability of the Geo-Con deep-soil-mixing equipment used for the in situ solidification (including continuity of operation, uniformity of mixing, and accuracy of column overlap).

3. Degree of soil consolidation (solidification) caused by the chemical additives.

4. Probable long-term stability and integrity of the solidified soil.

5. Costs for commercial-scale applications.

The following technical criteria were used to evaluate the effectiveness of the in situ stabilization/solidification process:

1. Mobility of the contaminants. Areas of high PCBs and VOCs were heavily sampled, with the analytical emphasis on leaching characteristics. Three leach tests were performed: the Toxicity Characteristic Leaching Procedure (TCLP) and two other leach tests, MCC-1P and ANS 16.1, which evaluate performance in solidified blocks. Only the effectiveness on PCBs was evaluated, as the additive was not designed to immobilize other contaminants. Permeabilities also were measured before and after soil treatment. These values indicate the degree to which the material permits or prohibits the passage of water through the soil mass, and thus the degree of water contact with the contaminants.

2. Durability of the solidified soil mass. Core sections from the solidified mass were analyzed to determine uniformity and long-term endurance potential. However, if a chemical bond forms between HWT-20 and the PCBs, as claimed by IWT, then maintaining durability of the solidified mass to prevent the mobility of the contaminant becomes less important. The analyses obtained information on the following:

- Integrity of the remediated soil.

- Unconfined compressive strengths, which provided an indication of long-term durability.

- Microstructural characteristics, which provided information on treated soil porosity, crystalline structure, and degree of mixing. This provided information on the potential for long-term durability of the hardened mass.

- Wet/dry and freeze/thaw weathering tests, which provided information on weight loss. Permeability and unconfined compressive strength tests of the weathered samples also were performed. These tests provided a measure of short-term durability.

1.2 PROCESS DESCRIPTION

IWT claims that their HWT-20 additive generates a complex crystalline connective-network of inorganic polymers. Structural bonding in the polymer is mainly covalent. There is a two-phased reaction in which the contaminants are complexed, first in a fast-acting reaction, and then permanently complexed further in the building of macro-molecules, which continue to generate over a long period of time. The bonding characteristics and durability of the structure are adapted by varying the composition of the HWT additive to suit a particular situation.

The Geo-Con/DSM deep soil mixing system of mechanical mixing and injection consisted of one set of cutting blades and two sets of mixing blades attached to a vertical drive auger, which rotated at approximately 15 rpm. Two conduits in the auger allowed for the injection of the additive slurry and supplemental water. HWT-20 additive injection was on the downstroke, with further mixing occurring on auger withdrawal. The treated 36-in.-diameter soil columns were positioned in an overlapping pattern (see Figure 1). In each sector, alternating primary and secondary soil columns existed, with all the primary columns prepared before the secondary columns were augered. Thus, the secondary soil columns were drilled between treated soil columns and represented only 75% new area relative to the primary columns. Geo-Con indicates that this is a more efficient method of soil treatment.

A batch mixing system processed the feed additives. HWT-20 powder was conveyed by air from a supply truck to a storage silo. To treat three or four soil columns, a measured amount of water was fed to a 1,000-gallon mixing tank. The HWT-20 was fed to the tank at a weight ratio to water of 4:3. A screw pump then pumped the slurry to the auger. Water was fed separately to the drill rig on a ratio basis to the additive slurry. Sufficient water was provided to produce a final soil product containing 1.6-1.7 lb of water/lb of HWT-20. For the Demonstration Test, sodium silicate was added to the bottom 3-4 ft of each column to provide a quick-setting boundary layer. The IWT technology does not consider this addition of sodium silicate as part of their process.

1.3 SAMPLING AND ANALYSIS PROGRAM

Soil sampling, provided by EPA, was performed two weeks before, and five weeks after, the remediation of the test sectors. Sampling was carried out at soil column centers, at column interfaces, and at five locations around one anticipated hot spot in each sector. Samples were taken at three or four depths, from the top layer of unconsolidated sand, the limestone layer, and the lower unconsolidated sand layer. Sampling in Sector B also was done in the sodium silicate boundary layer.

Chemical analyses were performed to identify and quantify soil contaminants in both the untreated and treated soil, as well as oil and grease and total organic carbon in the untreated soil. In addition, three different leaching tests were performed:

- TCLP - a commonly accepted procedure for measuring leachability of both organics and inorganics.
- ANS 16.1 - simulates leaching from the intact solidified core, which models a condition of percolating water flow sufficiently rapid to prevent saturation.
- MCC-1P - simulates leaching from the intact solidified core in relatively stagnant groundwater (saturated) regimes.

These latter two tests were drawn from the nuclear industry and modified to suit hazardous waste analysis.

Samples of untreated and treated soil were taken for the following physical property measurements:

- Moisture content
- Bulk density
- Permeability
- pH (untreated soil only)
- Unconfined compressive strength (treated soil samples)
- Weathering - wet/dry and freeze/thaw (for treated soil samples).

In order to obtain additional information on potential long-term integrity, microstructural studies were performed on the untreated and treated soils. These analyses included:

- X-ray diffractometry - to identify crystalline structures.

- Microscopy - use of scanning electron microscopy and optical microscopy to characterize porosity, hydration products, and fractures.

1.4 RESULTS AND DISCUSSION

The following observations were made:

- The chemical analyses of the untreated soils showed the highest PCB concentration (Aroclor 1260 - a set of known ratios of PCB congeners) which in Sector B was 950 mg/kg, while the maximum in Sector C was 150 mg/kg. The maximum value for the treated soil was 170 mg/kg, with all other values 110 mg/kg or less. The untreated soil at sample locations B-6, B-7, and B-8 also contained large quantities of volatile organic compounds (xylenes, chlorobenzene, and ethylbenzene) from 160 to 1,485 mg/kg total, and some heavy metals -- lead, copper, chromium, and zinc -- up to 5,000 mg/kg total metals. In the treated soil, the total VOCs ranged from 2 to 41 mg/kg and the total metals, 80 to 279 mg/kg. The large observed changes were likely due to a combination of factors. The largest was probably the vertical and horizontal mixing, which blended low and high contaminant concentration soils.

- The untreated-soil TCLP leachates showed PCB concentrations (Aroclor 1260) up to 13 μg/L. Leachates of all untreated soil samples, which had PCB concentrations below 63 mg/kg, were below the PCB detection limit of 1.0 μg/L, and all soil samples with PCB concentrations above 300 mg/kg showed detectable PCB concentrations in the leachate. For the soil samples with PCB concentrations between 63 and 300 mg/kg, some leachate samples had detectable quantities, but others did not. All leachates of treated soil samples were below 1.0 μg/L, the detection limit used for all samples. Seven treated soil leachates were analyzed a second time with the detection limit reduced to 0.1 μg/L, and four of the samples were also below this detection limit. Thus, the IWT additive appears to immobilize PCBs, but because of the very low values of PCBs being measured, it cannot be confirmed by this project.

- The VOC concentrations in the untreated-soil TCLP leachates ranged from 2,490 to 7,890 μg/L. The VOC concentrations in the treated soil leachates ranged from 325 to 605 μg/L. This reduction in VOC concentrations may have been due to a combination of factors, the main one being the reduction of concentration due to the horizontal and vertical mixing.

- The total heavy metal concentrations in the TCLP leachates ranged for the untreated soil from 320 to 2,650 μg/L, and for treated soil from 120 to 210 μg/L. As with the VOCs, this reduction in metals concentration in the leachate may have been a result of the reduction of metals concentration in the soils caused by the Geo-Con mixing operation.

- For the special leach tests, ANS 16.1 and MCC-1P, performed on treated soil samples, PCBs and VOCs were not detected in any of the leachates, even though the maximum contact time for the MCC-1P was 28 days.

- The oil-and-grease and total-organic-carbon contents of the untreated soil were each approximately 0.1 wt%, except at sample locations B-6, B-7, and B-8, where values up to 1.5% by wt. were measured. These results show a soil of very low organic content, which should not interfere with the cement hydration reactions.

- The bulk density of the soil increased 21% after treatment. The volume increase of 8.5% was small and was equivalent to a ground rise of approximately 18.4 inches in Sector B and 14.3 inches in Sector C. This agreed with the general observations made by the test observers.

- The unconfined compressive strength (UCS) measured in both sectors was quite satisfactory, easily meeting the EPA guideline minimum of 50 psi. In Sector B the range was from 75 to 579 psi. In Sector C the range was from 247 to 866 psi. Overall, Sector C samples had a higher average UCS of 536 psi compared to Sector B, with an average UCS of 288 psi. Two factors that may have contributed to the UCS difference are: the higher additive-injection rate in Sector C, and some areas that were poorly treated because of insufficient column overlap near sample points in Sector B. However, because the degree of overlap of the treated soil columns in Sector C was not measured, the second factor may not be valid.

  In addition, for both sectors, the UCS appeared to increase with depth. In Sector B, samples taken from the center of primary columns gave the highest UCS. In Sector C, samples from the center of the primary columns and column interface areas gave approximately equal values of UCS, while secondary column centers gave higher values.

- The average permeability of the untreated soils was 1.8 x 10^{-2} cm/s, and ranged from 0.1 x 10^{-2} to 12 x 10^{-2} cm/s. Initial results obtained for the treated soil were 10^{-6} to 10^{-7} cm/s. Most of these values meet the EPA guideline of 10^{-7} cm/s for the maximum allowable value for hazardous-waste landfill liners. However, the four-orders-of-magnitude decrease in permeability achieved by this treatment will cause the groundwater to flow around, not through, the treated block.

- The wet/dry weathering test results were satisfactory. They showed very low weight losses -- 0.25 to 0.50% for the twelve-cycle tests. The relative weight losses of test specimens to controls were very small, averaging about 0.1%. The freeze/thaw tests showed large losses -- up to 30.70 wt%. However, these apparent large freeze/thaw test-specimen degradations may not affect the mobility of PCBs if chemical bonding exists, as claimed by IWT. The weight loss of the controls was 0.25% to 0.70%. The unconfined compressive strengths of the wet/dry test specimens after 12 cycles of weathering were the same as for the unweathered samples. For the freeze/thaw specimens where weight losses exceeded 3%, the UCS values decreased dramatically, approaching zero for some samples. Permeabilities performed on four weathered samples with low-to-moderate weight losses are equivalent to those for unweathered samples. In addition, IWT has indicated that they can adjust the additive mix formulation to be resistant to freeze/thaw conditions. This would be done for locations where the climate is much more severe than in Florida.

- o The microstructural analysis, performed on each sample, showed that the IWT process produced a dense, homogeneous mass with low porosity. It also showed that structural variation in the vertical and horizontal directions were absent, which indicated that mixing was quite satisfactory. In addition, needles of ettringite were quite common, occurring in greater amounts than observed in a Portland cement sample of typical water/cement ratio of 0.4. The presence of large amounts of ettringite in a Portland cement sample is a symptom of sulfate attack, which can in some cases lead to a structural failure due to expansion. The sulfate at Hialeah comes from the HWT-20 additive and from gypsum found in the untreated soil. It is not known whether the ettringite observed in the treated soils will necessarily lead to expansive failures, as it is claimed to be a part of the IWT chemical fixation technology. The presence of ettringite may in fact, according to Professor Perry in London (see Appendix D), aid the immobilization of metals.

- o The addition of additive, water, and sodium silicate increased the soil weight by an average of 32%. The average additive addition was 0.171 lb/lb dry soil in Sector B, and 0.193 lb/lb dry soil in Sector C (compared to the targeted values of 0.131 lb/lb dry soil and 0.150 lb, respectively). In Sector B, the dosage of additive for the secondary columns was reduced compared to the primary columns, by almost 30%.

- o The demonstration operations lasted six days -- three days on each sector. Operations were well organized and ran smoothly, although some minor difficulties were encountered, including the following:

  - The locations of the soil columns deviated from the planned points, and some untreated areas between columns exist; Geo-Con has indicated that their auger actually creates a column slightly greater in diameter than 36 in., which would reduce the untreated areas.

- Automatic feed control could not be maintained.
- A major water leak occurred at the drill head, precluding the use of supplemental water for the last 21 columns. To save time, Geo-Con was instructed to continue without repairing the leak.
- Sodium silicate was not fed uniformly and was mixed with more soil than originally intended.

Since the feed system was designed for a 4-auger commercial unit and given the experience gained by Geo-Con, these minor difficulties should be readily eliminated during a large-scale commercial operation.

- The estimated remediation cost with operation of the 1-auger machine used for the demonstration is \$194/ton (\$150/yd^3). For larger applications, using Geo-Con's 4-auger machine, costs would be lower.

SECTION 2

INTRODUCTION

2.1 BACKGROUND

Concern by the public and government is growing over using landfills for the containment of hazardous wastes. In response to the Superfund Amendments and Reauthorization Act of 1986 (SARA), the Office of Research and Development (ORD) and the Office of Solid Waste and Emergency Response (OSWER) of the Environmental Protection Agency (EPA) have established a formal program to accelerate the development, demonstration, and use of new or innovative technologies. This program is called Superfund Innovative Technology Evaluation, or SITE.

The major objective of the SITE Program is to develop reliable cost-and-performance information on innovative alternative technologies, so that they can be adequately considered in Superfund decision making. SITE demonstrations usually will be conducted at uncontrolled hazardous-waste sites, state sites, sites under the aegis of federal agencies, developers' sites, and commercial installations.

The two technologies evaluated were the International Waste Technologies (IWT) in situ stabilization/solidification process, and the Geo-Con, Inc. deep-soil-mixing equipment. It is claimed that these technologies may be used together to create a hardened, leach-resistant, concrete-like solidified mass. This was the first field demonstration of an in situ stabilization/solidification process. The demonstration to evaluate these technologies was performed in April 1988 at a General Electric (GE) electric service shop in Hialeah, Fla. on two 10x20-ft test sectors known to be contaminated with polychlorinated biphenyls (PCBs). GE is required by the local regulatory authority -- Metropolitan Dade County Environmental Resources Management (MDCERM) -- to remediate the site for PCBs. However, the objectives of this SITE project -- as defined in the demonstration plan and the approved Quality Assurance Project Plan (QAPP) -- were much broader than those of GE to meet their obligations to MDCERM. This expanded effort included three different leaching procedures, physical and microstructural tests, and analyses for volatile organic compounds (VOCs) and heavy metals in leachates if these contaminants were detected in the untreated soil.

The regulatory authority (MDCERM), responsible for the Hialeah site, mandated the tests on the two sectors for the remediation of PCBs before the site cleanup. IWT, the technology developer, who provided the proprietary additive, and Geo-Con, Inc. who provided the specialized drilling equipment, were contractors to GE for the site remediation. In addition, under a cooperative agreement with EPA, IWT was designated as the SITE project technology developer for the demonstration; Geo-Con, Inc. verbally agreed that its in situ procedures were to be evaluated.

GE owns an electric service shop in Hialeah, Fla., which it operated from 1958 to 1984. The property, located in a light industrial neighborhood, is approximately 210 x 132 ft. The service shop is a one-story building approximately 100 x 120 ft in plan. There is a low 60-ft-wide bay on the eastern side of the building with masonry-block load-bearing walls. On the western side a high 40-ft-wide bay area of steel frame was added a few years later.

PCBs were detected in the near-surface soils in early 1984 when the shop was being closed. A cleanup effort was conducted in March 1984 and March 1985. This involved removal of approximately 700 yd^3 of soil, which eliminated more than half of the PCBs, and replacing it with clean fill. Observations during the initial soil-removal work, which extended down nearly 5 ft (the approximate depth to groundwater at that time), showed staining and apparently oily materials in the bottom of the excavation adjacent to the concrete pad on the east side of the building. The presence of PCB oils (primarily Aroclor 1260) was suspected. This suspicion resulted in GE's initiating a five-phased study of the extent of PCBs in the subsurface. This phased exploration progressively added sampling points to define the zones where data indicated PCB concentrations above 50 ppm. Overall, 536 soil samples were analyzed for PCBs. A water sample from each of the onsite and offsite monitoring wells was analyzed for PCBs and VOCs that are on the National Pollution Discharge Elimination System (NPDES) list.

2.2 PROGRAM OBJECTIVES

The major objectives of this SITE project for the in situ stabilization/solidification of the soils at the GE electric service shop, using the IWT process and the deep-soil-mixing equipment of Geo-Con, Inc., were to determine the following:

1. Ability of the stabilization/solidification technology to immobilize the PCBs. Extensive sampling around two of the remaining high-concentration areas of PCB contamination was performed. If VOCs and heavy metals were detected in the soil, the ability of the process to immobilize these contaminants was also to be evaluated.

2. Effectiveness, performance, and reliability of the Geo-Con deep-soil-mixing equipment used for the in situ solidification.

3. Degree of soil consolidation (solidification) caused by the chemical additives.

4. Comparative effectiveness of the stabilization/solidification for unconsolidated sand and limestone beds at the site; comparative effectiveness above and below the water table (5-7 ft below grade).

5. Continuing integrity of the solidified soil and immobilization of the organics over a period of five years. (Long-term data will be collected.)

6. Costs of applying this technology to commercial-size installations and for use at Superfund sites.

7. Viability of the technology for use at other sites.

2.3 TECHNOLOGY EVALUATION CRITERIA

The following criteria were used to evaluate the effectiveness of the IWT in situ stabilization/solidification process used at the GE site:

1. The effectiveness in immobilizing the PCBs was determined from leaching and permeability tests. Areas of high PCB concentrations were extensively sampled, before and after treatment, with the analysis emphasis placed on leaching characteristics. Three leachability tests were performed: the Toxicity Characteristic Leaching Procedure (TCLP), which required grinding of the solidified treated soil; and leach tests MCC-1P and ANS 16.1, which simulated the solidified condition that exists after soil treatment.

   Permeability was measured, to indicate the rate of movement of water through the soil mass, and thus the quantity of water contacting the contaminants in the treated and untreated soil. Typical unconsolidated soils have a permeability of 10^{-2}-10^{-3} cm/s. A reduction to less than 10^{-7} cm/s, a value considered satisfactory by EPA for soil barrier liners in landfills, would indicate the process produced a highly impermeable soil mass.

2. The durability of the in situ solidified-soil-mass and its long-term endurance potential was indicated by analyzing portions of the solidified mass to determine uniformity at the time of sampling. However, if chemical bonding occurred, as claimed by IWT, durability and some of the physical test results would become less important. Information was gathered as follows:

   (a) Samples were taken at remediation column-overlap areas as well as at column centers to identify areas of low integrity due to poor overlap or inability to solidify.

(b) Unconfined compressive strength (UCS) was measured. The results provided an indication of the degree of uniformity of the mixing of soil and additive. The laboratory UCS data previously obtained by GE and the EPA in 1986 and 1987 were used as a baseline.

(c) X-ray diffraction and microscopy studies were performed to determine microstructural characteristics. These samples provided information on treated soil porosity, crystalline structure, and degree of mixing.

(d) Core samples taken during the borings were visually inspected for cracks and void zones, which may cause degradation of the monolith over many years.

(e) The weight loss during freeze/thaw and wet/dry weathering tests provided an indication of treated soil durability. In addition, the results for the UCS and permeability tests performed after the 12 weathering cycles provided additional evidence on potential durability of the treated soil.

(f) The difference between soils above and below the water table, and variations in properties of treated soils from the sand and limestone layers were determined, providing information on the range of soils that can be processed.

In addition, a long-term monitoring program, designed to collect treated soil samples over a five-year period, will provide more information on the durability of the treated soil.

2.4 DESCRIPTION OF OPERATIONS

Two sectors (designated B and C), each approximately 10 x 20 ft, were remediated -- one to a depth of 18 ft, and the other to a depth of 14 ft. These depths were defined by GE to treat all the soil containing at least 1.0 mg/kg of PCBs. The IWT additive was injected into the soil as a slurry at a nominal rate of 0.15 lb of dry additive per lb of dry contaminated soil.

The additive was air-conveyed from a supply truck to a storage silo. It then was slurried with water at a ratio of 4:3 solids to water in a 1,000-gal mixing tank. The slurry then was pumped to the drill rig. Water also was fed to the drill rig at a constant ratio to the slurry, depending on water content of the soil. For the bottom 3 ft of the injection column, sodium silicate was added along with the additive to provide a fast-setting boundary layer. Although the IWT process does not require any addition of sodium silicate, this was done at the request of GE.

The Geo-Con/DSM drill rig provided the soil mixing, with the additives injected through piping at the bottom of the mixing auger. The auger contained one set of cutting blades and two sets of mixing blades, each 1 ft apart, at the bottom of the shaft. The additive was injected on the downstroke and mixed into the soil, with additional mixing occurring on the upstroke.

The DSM machine was tracked into position and the horizontal and vertical alignments checked. The elevation measurements were made by using a small tracking wheel attached to a digital tachometer. Machine location was verified by the use of a stationary laser.

2.5 PROJECT ORGANIZATION

For the SITE Project demonstration, a Cooperative Agreement was signed between EPA and IWT. In addition, GE provided the test site, and Geo-Con, GE's site remediation contractor, was responsible for injecting the additive, provided by IWT as a dry powder.

SECTION 3

SUMMARY OF PERFORMANCE DATA AND EVALUATION

This SITE project obtained a large amount of analytical and operating data. It showed that PCBs, the primary contaminant at the site, were probably immobilized and the physical properties of the solidified mass were satisfactory. Operation of the equipment was quite satisfactory, with only minimal and correctable difficulties encountered. Results from the samples collected showed an homogeneous mix with low porosity. Wide variations in physical and chemical properties were not observed within the limitations of the sampling and analysis program.

The results, summarized below, provide evidence of meeting most of the program objectives. See Section 8 for a detailed discussion.

1. The TCLP leaching tests for treated soil samples showed no PCBs in the leachate for the samples analyzed to a detection limit of 1.0 µg/L. However, seven of the TCLP leachate analyses were repeated to a detection limit of 0.1 µg/L, and four of the values were below the new detection limit. For the untreated soil, all leachates of soils containing 300 mg/kg PCBs or more showed some PCBs, up to 13 µg/L (except for one at 400 µg/L), as did some soil sample leachates for soils containing between 63 and 300 mg/kg PCB. The maximum treated-soil concentration for PCBs was 170 mg/kg (in Sector B), with all except two samples at 100 mg/kg or less. Tables 10 and 11 present these results. From the data available, it appears that the process immobilizes PCBs, but since the leachate results are so close to the PCB detection limits, confirmation of PCB immobilization in this SITE project is difficult.

2. The VOCs (xylenes, chlorobenzene, and ethylbenzene) in the untreated soil leachates ranged from 2,490 to 7,890 µg/L. The total VOCs in the treated soil leachates, where the treated soil concentration ranged from 2.4 to 41 mg/kg, ranged from 325 to 605 µg/L. The three VOCs -- xylenes, chlorobenzene and ethylbenzene -- had leachate concentrations that were reduced essentially equally, from untreated to treated soil samples. However, according to IWT, the composition of HWT-20 used was designed only for PCBs, not VOCs. The results are summarized in Table 12.

3. The combined metals concentrations in the untreated soil leachate ranged from 0.32 to 2.65 mg/L. For the treated soil, the combined leachate concentration was 0.1 to 0.2 mg/L. These results are shown in detail in Table 13.

4. PCBs and VOCs were not detected in any of the leachates from the special leach tests, MCC-1P and ANS 16.1.

5. The oil-and-grease and total-organic-carbon contents of the soil were very low and were approximately 0.1 wt%, except at sample locations B-6, B-7, and B-8, where values up to 1.5 wt% were measured. An organic content of about 10% or more by wt. would cause significant hindrance of the cement hydration reaction. Thus, the organic content of up to 1.5 wt% was too low to interfere with the cement hydration reaction.

6. The volume increase of the treated soil was low -- 8.5%. On average, the bulk density increased from 1.55 g/mL (96.7 lb/ft^3) to 1.88 g/mL (117.3 lb/ft^3) for a soil weight increase of 32%.

7. The treated soil permeability results were in the range of 10^{-6} to 10^{-7} cm/s. These values were slightly higher than the targeted value for hazardous-waste landfill liners of 1×10^{-7} cm/s, but showed a major improvement over untreated soils. The untreated soil averaged about 1.8×10^{-2} cm/s and ranged from 0.05×10^{-2} to 24×10^{-2} cm/s. See Tables 5 to 8 for more details.

8. The unconfined compressive strength (UCS) was quite satisfactory. In Sector B the values ranged from 75 to 579 psi, averaging 288 psi. The values in Sector C ranged from 247 to 866 psi, averaging 536 psi. These values indicate that sufficient load-bearing strength will occur, since the usual criterion on minimum strength requirements recommended by EPA is 50 psi. See Tables 6 and 7 for more details.

   In addition, for both sectors, UCS appeared to increase with depth. In Sector B, samples taken from the center of primary columns gave the highest UCS. In Sector C, samples from the center of the primary columns and column interface areas gave approximately equal values of UCS, while values at secondary column centers were higher. The HWT-20 injection rate was higher in Sector C -- 0.193 lb additive/lb dry soil versus 0.171 lb in Sector B, but this difference probably would account for only part of the difference in UCS seen. Possible additional factors may be uniformity of the additive injection and lack of correspondence between sample core locations and treated-soil column locations.

9. Wet/dry weathering test results showed very low weight losses -- 0.25 to 0.50% for the twelve-cycle tests. The weight losses of test specimens relative to controls were very small. For the freeze/thaw tests, major weight losses -- up to 30.7% -- were encountered, with the overall average being 6.5%. This degradation may not affect contaminant mobility if chemical bonding exists as claimed by IWT. The

weight loss of the controls was 0.25% to 0.70%. The UCS tests performed on many of the weathered samples showed some loss of UCS when the weight loss was above 3%. IWT has indicated that they can adjust the additive mix formulation to be resistant to freeze/thaw conditions. This would be done for locations where the climate is much more severe than in Florida.

For the three largest weight-losses (above 27%) the strength was zero. These results are provided in detail in Tables 7 and 8.

10. The microstructural studies showed the following:

    - The treated soil produced a dense, homogeneous mass with low porosity.
    - Ettringite was common to all samples and was often present in larger amounts than observed in hydrated Portland cement. It was the intent of IWT, in the design of their HWT-20 additive, to produce ettringite, thus explaining the unexpectedly high quantities seen.
    - Significant differences in hydration products from quartz-rich and calcite-rich samples were not observed, indicating the cement-based reactions were the same in both soil layers.

11. The two plant sectors selected for treatment were approximately 20 x 10 ft and, based on prior sampling, were expected to be high in PCBs. These areas were selected by the owner for the evaluation of the remediation technology and, concurrently, were used for the SITE Program.

    Sector B contained PCBs up to 950 mg/kg (in the untreated soil); one localized area was high in VOCs, with some heavy metals. The maximum total VOC and total heavy-metals concentrations measured were 1,485 and 5,000 mg/kg, respectively. In Sector C, the maximum PCB concentration measured was 150 mg/kg, and no significant VOCs or heavy metals were detected.

12. Total addition of additive, water, and sodium silicate increased the soil weight by 32%. The average additive addition was 0.171 lb additive/lb dry soil in Sector B, and 0.193 lb in Sector C, compared to the targeted values of 0.131 lb and 0.150 lb, respectively. In Sector B, the dosage of additive for the secondary columns was reduced compared to the primary columns almost 30%.

13. The demonstration lasted six days, with the operations performed in a very satisfactory manner. However, some difficulties did occur that may have impacted on the stabilization/solidification process. These were as follows:

- The soil columns deviated from targeted locations, and areas of untreated soil occurred. However, Geo-Con has indicated that its auger actually creates a column of a diameter greater than 36 in., which would reduce the anticipated untreated area.

- Automatic feed control of additive and wastes could not be maintained, resulting in lean and rich injection areas. Manual control was the predominant technique used. This difficulty was caused in part by trying to adapt a system designed for the larger 4-auger commercial unit to the 1-auger unit used in the demonstration.

- A water leak at the auger head occurred, necessitating elimination of the supplemental water for the final 21 soil columns. To save time, Geo-Con was instructed by GE to continue without repairing the leak.

- Sodium silicate was not fed uniformly and was mixed with more soil than originally intended.

14. The cost of remediation was $194/ton ($\$150/\text{yd}^3$), based on input from IWT and Geo-Con for the 1-auger unit. For larger applications, using Geo-Con's 4-auger machine, costs would be lower.

SECTION 4

PROCESS DESCRIPTION

The IWT in situ stabilization/solidification process used the equipment of Geo-Con, Inc. for injecting the HWT-20 additive. The additive was injected and mixed into the soil to provide a solidified mass that was intended to immobilize the contaminants and provide a long-lasting durable mass of low permeability. The following sections provide descriptions of the chemistry of the IWT additive and of the equipment of Geo-Con.

4.1 REACTION MECHANISMS

International Waste Technologies (IWT) provided the following description of the process chemistry from their literature:

The Hazardous Waste Treatment (HWT) set of chemical fixation or detoxification products generates a complex crystalline, connective-network of inorganic polymers. These macromolecules are made up of selected polyvalent inorganic elements that react to produce branched and cross-linked polymers of sufficient density to cause some interpenetrating polymer network (IPN) bonding. These polymers have a high resistance to acids and other naturally existing deteriorating factors. Structural bonding in the polymers is mainly covalent. There is a two-phased reaction, in which the toxic elements and compounds are complexed first in a fast-acting reaction, and then permanently complexed further in the building of macromolecules, which continue to generate over a long period of time.

The first phase of the chemical fixation reaction can be described as generating irreversible colloidal structures and chemical reactions with toxic metals and organics via special intercalation compounds. These are compounds that provide interactions between organics in the soil and the silicate-based molecules in the additive mix.

Phase Two -- the generation of the macromolecular framework -- is also a relatively irreversible colloid synthesis. However, this is a slower-moving reaction, going from solution to gel to crystalline three-dimensional inorganic polymer. The treated material should be able to pass the required leaching tests within 7 to 28 days. Of particular importance in the bonding of hazardous elements and compounds is the chemical reaction of the sulpho-ferri-aluminate hydrates. The bonding characteristics and durability of structure are achieved by varying the composition of the HWT treatment compound to suit a particular waste situation and the desired leaching standards.

IWT is performing extensive laboratory studies to prove and improve the capability of various HWT additives to bond to different contaminants. Various tests, such as Fourier transform infrared, differential scanning calorimetry, and thermo-gravimetric analyses are being performed.

4.2 EQUIPMENT SPECIFICATIONS

The Geo-Con/DSM system of mechanical mixing and injection consisted of a one-auger machine with one set of cutting blades and two sets of mixing blades attached to a vertical-drive auger. The blade rotated at approximately 15 rpm. Two conduits were constructed in the drive rod, and injection ports were provided at the bottom of the shaft so that the additive slurry and liquid (water or sodium silicate solution) could be injected into the zone being agitated by the rotating blades. To create a vertical column of treated soil, the blade was advanced to the desired maximum depth of treatment. The HWT-20 additive was injected in a slurry form, mixed into the soil and limestone as the blade rotated during entry into the soil, and mixed again on withdrawal from the ground. As necessary, additional cycles of injection and mixing were made along the length of the column to provide the required blending. Column positioning was planned to provide sufficient overlap to avoid untreated areas (see Fig. 1). The diameter of the treated soil column was 36 in. For larger remediations, Geo-Con can provide a 4-auger machine, where primary and secondary soil columns are prepared in groups of four.

The DSM machine was tracked into position, and the horizontal and vertical alignments were checked. The elevation measurements were made by using a small tracking wheel attached to a digital tachometer. This fixture was mounted at the top of the auger head and tracked the depth of the drill head. The tachometer output was shown on a digital display. Machine horizontal location was verified by use of a stationary laser. The vertical positioning of the suspended auger was controlled to about one-tenth of a degree.

A batch-mixing plant was located in the building high bay (see Fig. 2), to prepare and feed the additives. The equipment specifications are briefly described in Table 1. HWT-20 was conveyed from a supply truck by air to a storage silo. To treat three or four soil columns, a measured amount of water was fed to a 1,000-gal mixing tank. HWT-20 was added to the mixing tank at a weight ratio of 4:3 to water. A Moyno positive-displacement pump, rated at 120 gpm, then pumped the slurry to the drill rig. Since the nominal slurry requirements ranged from 10-20 gpm, the excess was recycled to the mix tank. The HWT-20 feed rate was designed for 15 lb of dry additive per 100 lb of dry soil.

Water was fed to the drill rig on a ratio basis to the slurry. This ratio varied with soil moisture content. At Hialeah this was based on whether the additive injection was above or below the water table. The final soil/HWT-20/water slurry was targeted to contain approximately 1.6-1.7 lb of water/lb of HWT-20. Sodium silicate was added at the bottom 3-4 ft of each column to provide a quick-setting low-permeability boundary-layer (this is not part of the IWT additive technology). The manually controlled ratio of sodium silicate to HWT-20 was about 0.05 on a dry weight basis. The sodium silicate was provided as an approximately 40% solution.

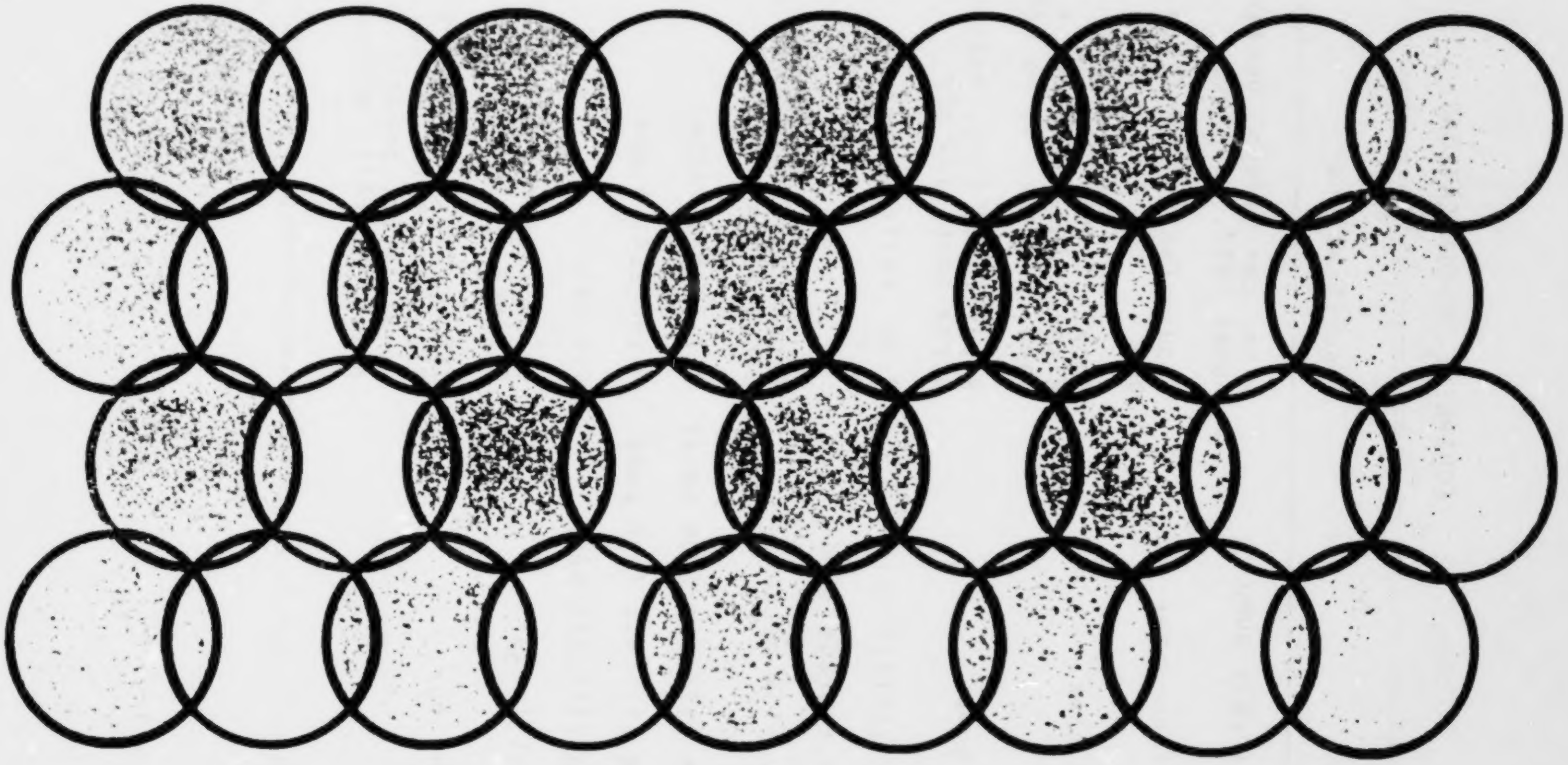
The control system consisted of the following:

- Water flow meter (totalizer), for flow to the slurry mix tank.
- HWT-20 rotary feeder, to feed additive from the storage silo to the mix tank.
- Magnetic flow meter, for measuring slurry flow to the drill rig.
- Flow meters (totalizers), for water and sodium silicate feeds.
- Control package that controls the ratio of slurry feed to the drill-rig auger-penetration rate, and water-to-slurry feed ratio.

Figures 3 to 7 are photographs of the process equipment.

TABLE 1. EQUIPMENT SPECIFICATIONS

Item	Specifications
1. Water supply pump	6-in. centrifugal Gorman Rupp, Model 1682, 800 gpm
2. Water flow meter	Liquid Controls Model M-7, 100 gpm
3. Mixing tank	Tank - 1,000 gal Mixer - Two-impeller, 4 blades each, 230 rpm, 10-hp motor
4. Grout pump	Roper 7x428 6-in. rubber-lined screw pump, 120 gpm
5. Slurry control valve	2-in. knife gate
6. HWT-20 storage silo	
7. Slurry flow meter	Brooks Wafer-Magnetic, Model 7402BIWICGAA
8. Sodium silicate flow meter	0.1-10 gpm range
9. Sodium silicate feed pump	Moyno 2L4, 5 gpm
10. Sodium silicate tank	150 gal
11. Reagent feeder	Delta Extended-Life Airlock-14-in. Rotary Feeder
12. Control box	I.S.E. Inc. - Monitors: Flowrate, total volume, total penetration, production rate, pitch and roll, pressure



Note: Shaded circles are primary columns, and non-shaded areas are secondary columns.

Figure 1. Overlapping column arrangement.

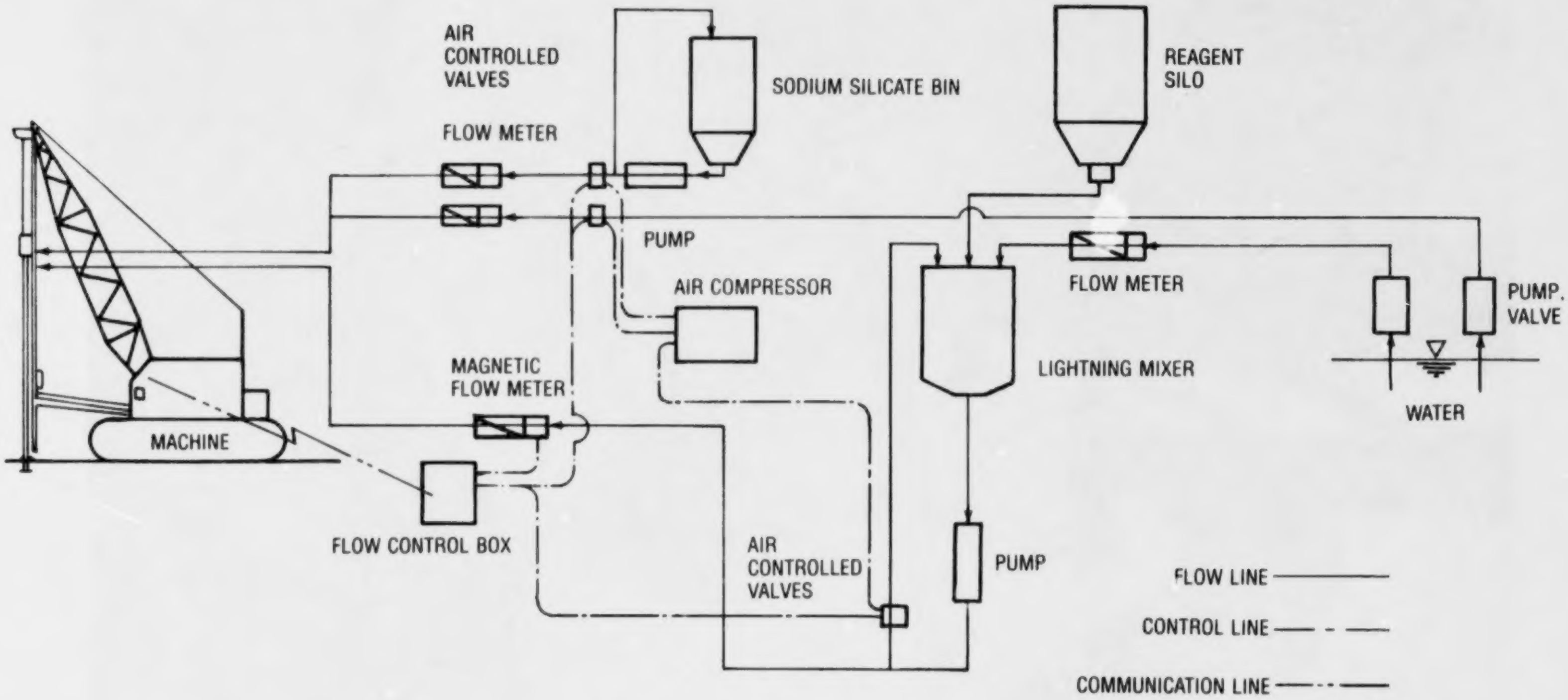

AIR
CONTROLLED
VALVES
SODIUM SILICATE BIN
REAGENT
SILO
FLOW METER
PUMP
AIR COMPRESSOR
FLOW METER
PUMP.
VALVE
LIGHTNING MIXER
WATER
MAGNETIC
FLOW METER
MACHINE
FLOW CONTROL BOX
AIR
CONTROLLED
VALVES
PUMP
FLOW LINE
CONTROL LINE
COMMUNICATION LINE

Figure 2. Batch mixing plant.

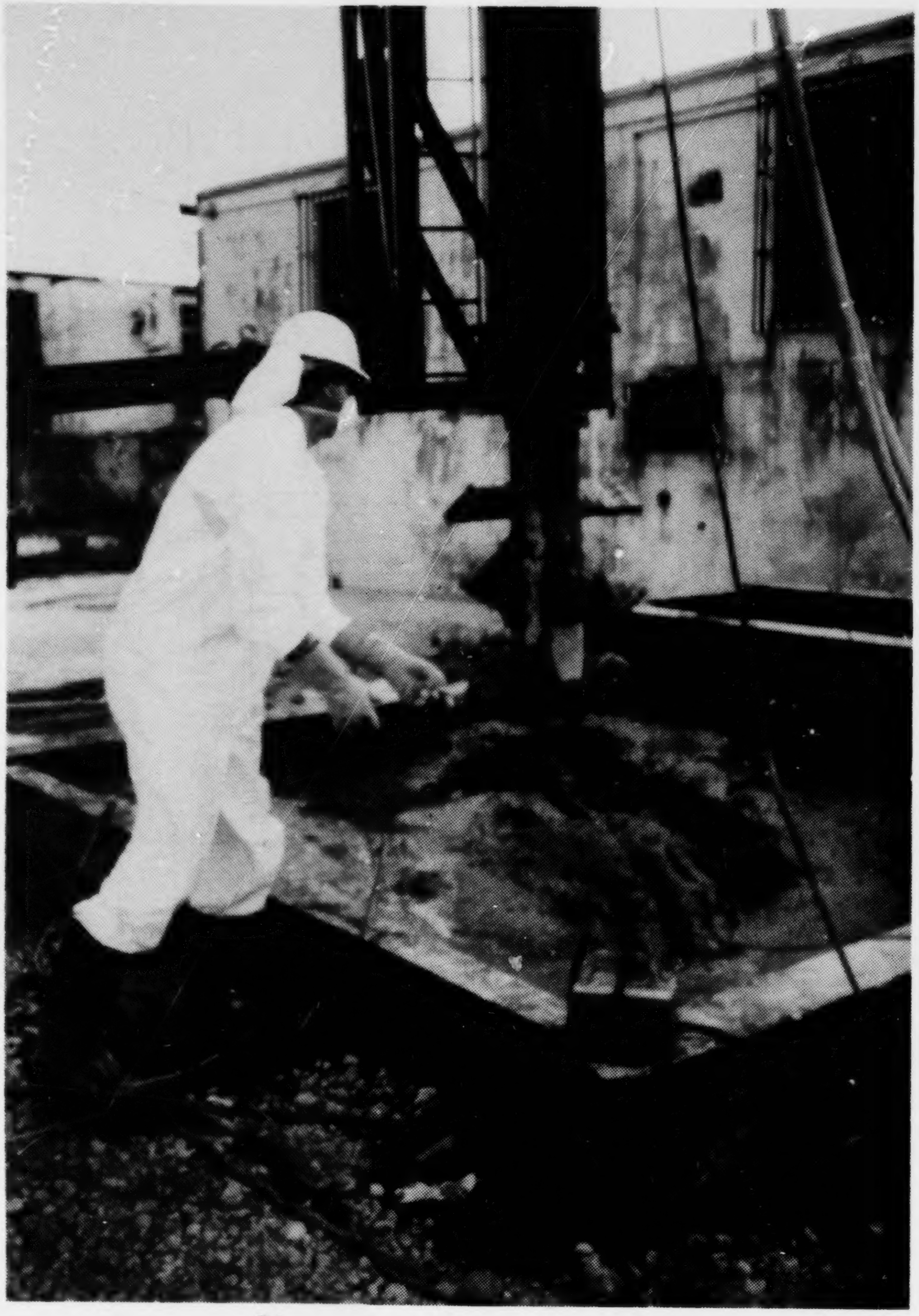


Figure 3. Soil mixing auger.

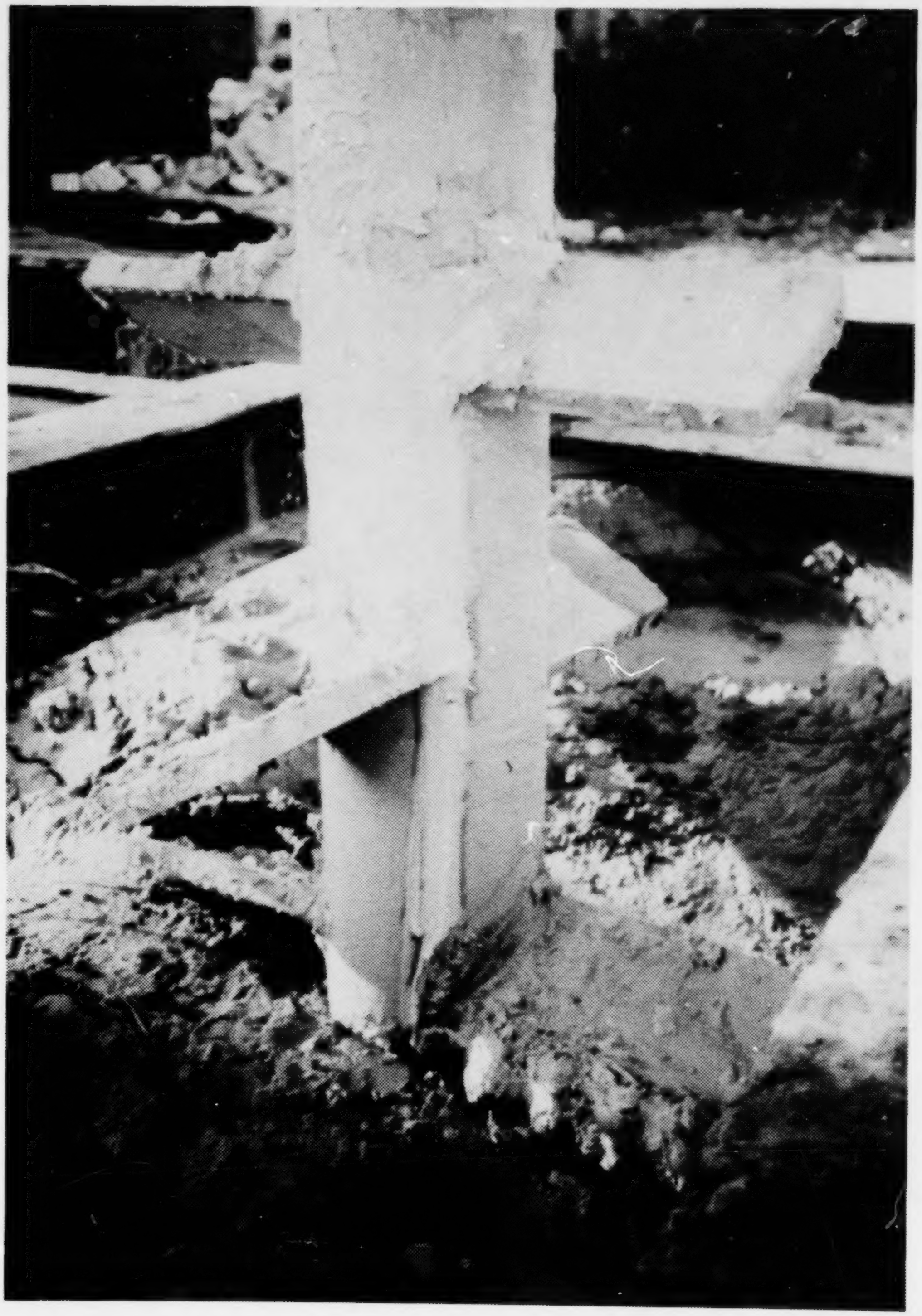


Figure 4. Mixing auger on downstroke.

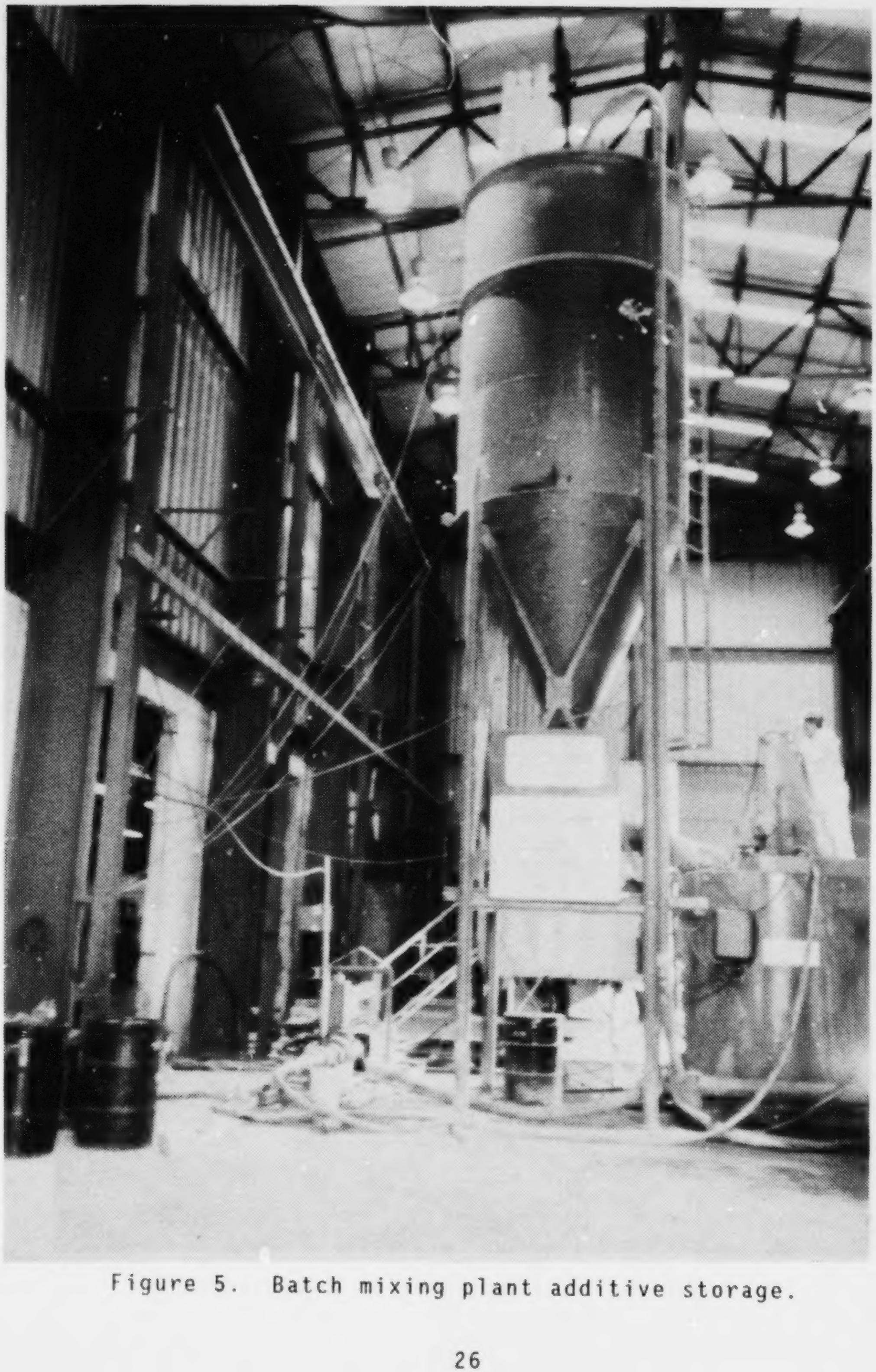


Figure 5. Batch mixing plant additive storage.

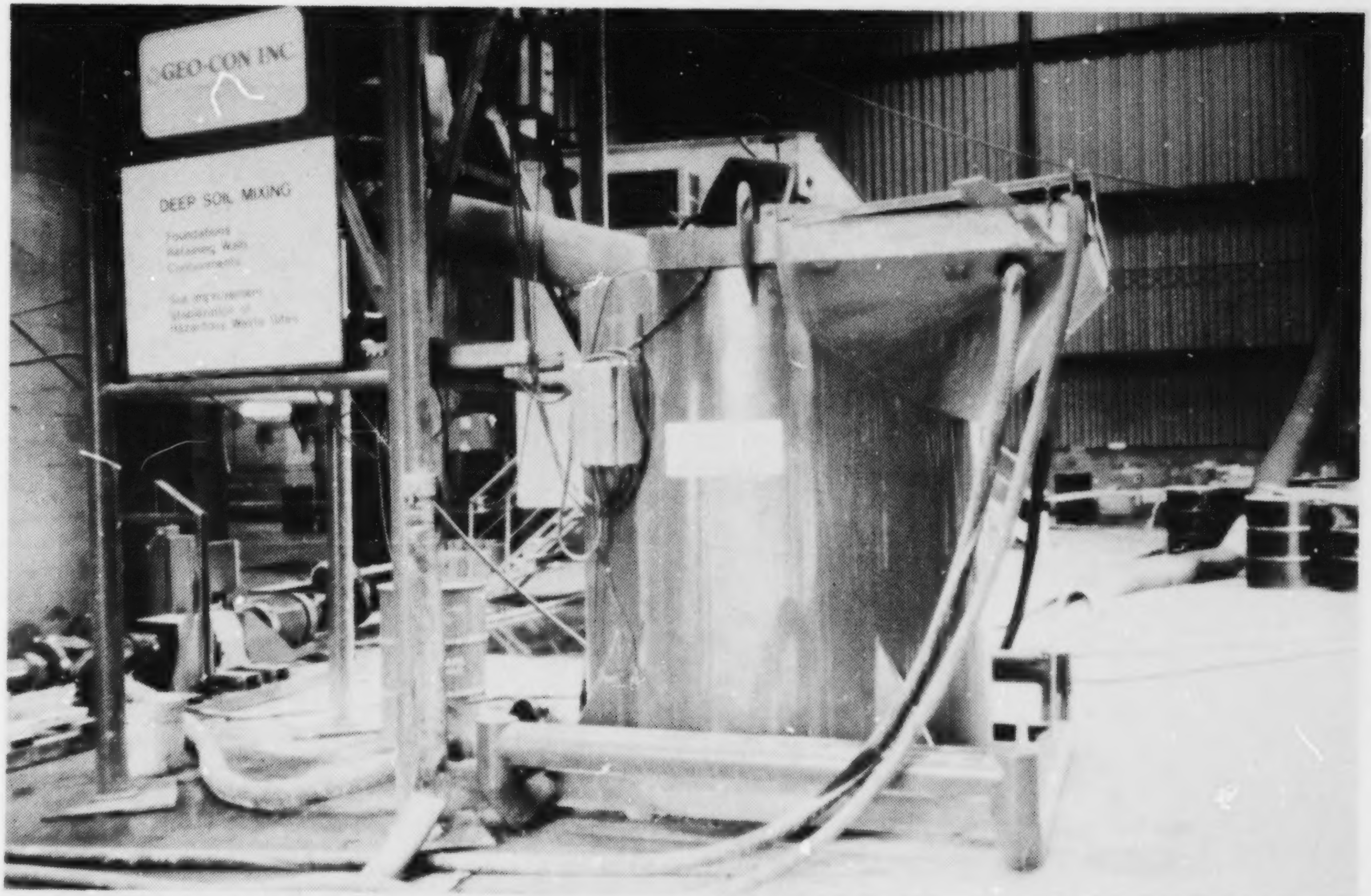

GEO-CON INC
DEEP SOIL MIXING

Figure 6. Slurry feed system.

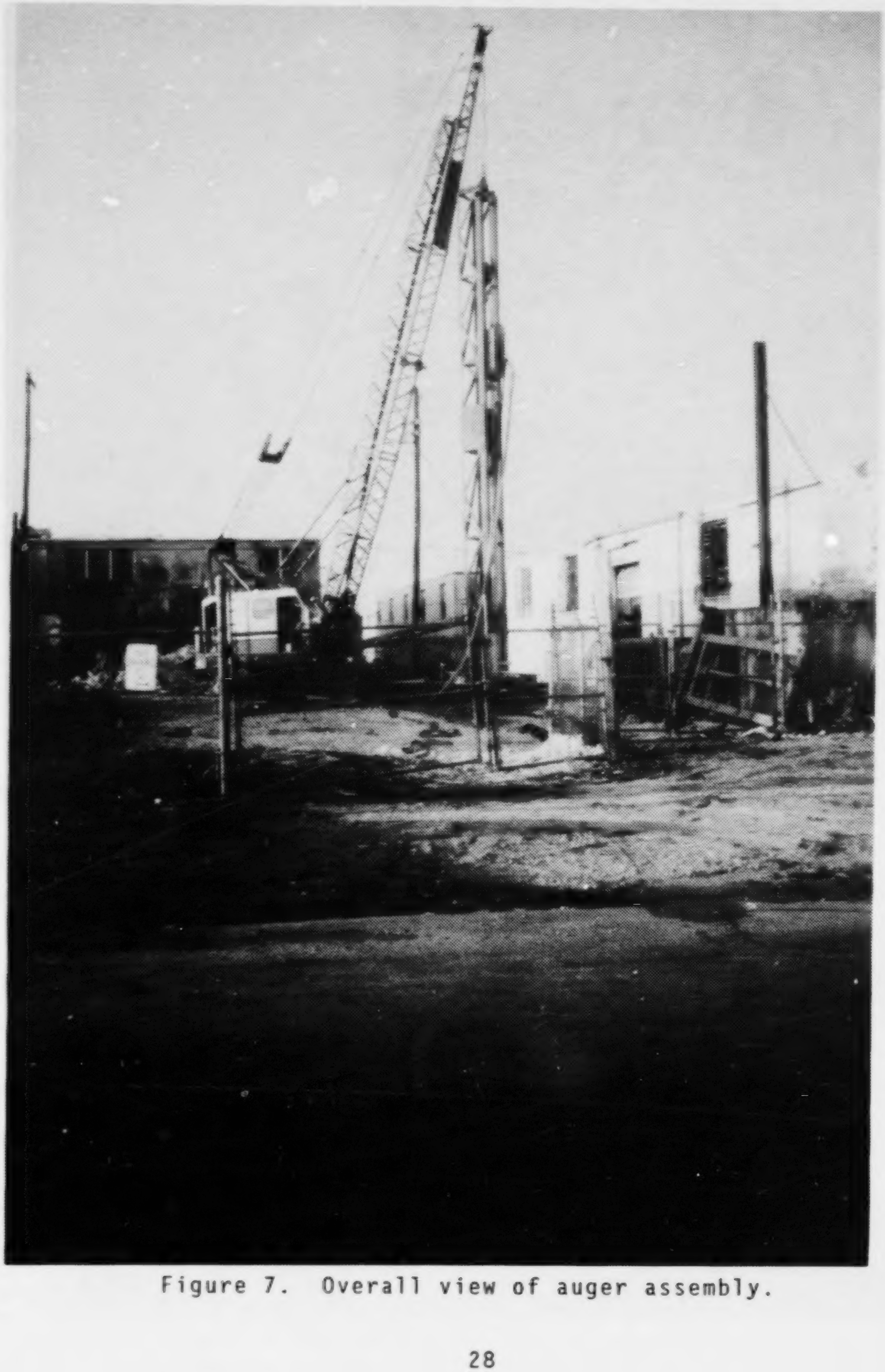


Figure 7. Overall view of auger assembly.

SECTION 5

SITE CHARACTERISTICS

5.1 SITE DESCRIPTION

The GE electric service shop is located in Hialeah, Fla., on 28th Street, just east of 10th Avenue. The property is 210 x 132 ft in plan. It is approximately 7-8 ft above sea level. The service shop consists of a one-story masonry-block building 60 x 120 ft in plan. A high bay of steel construction, 40 x 120 ft, exists on the western end of the building.

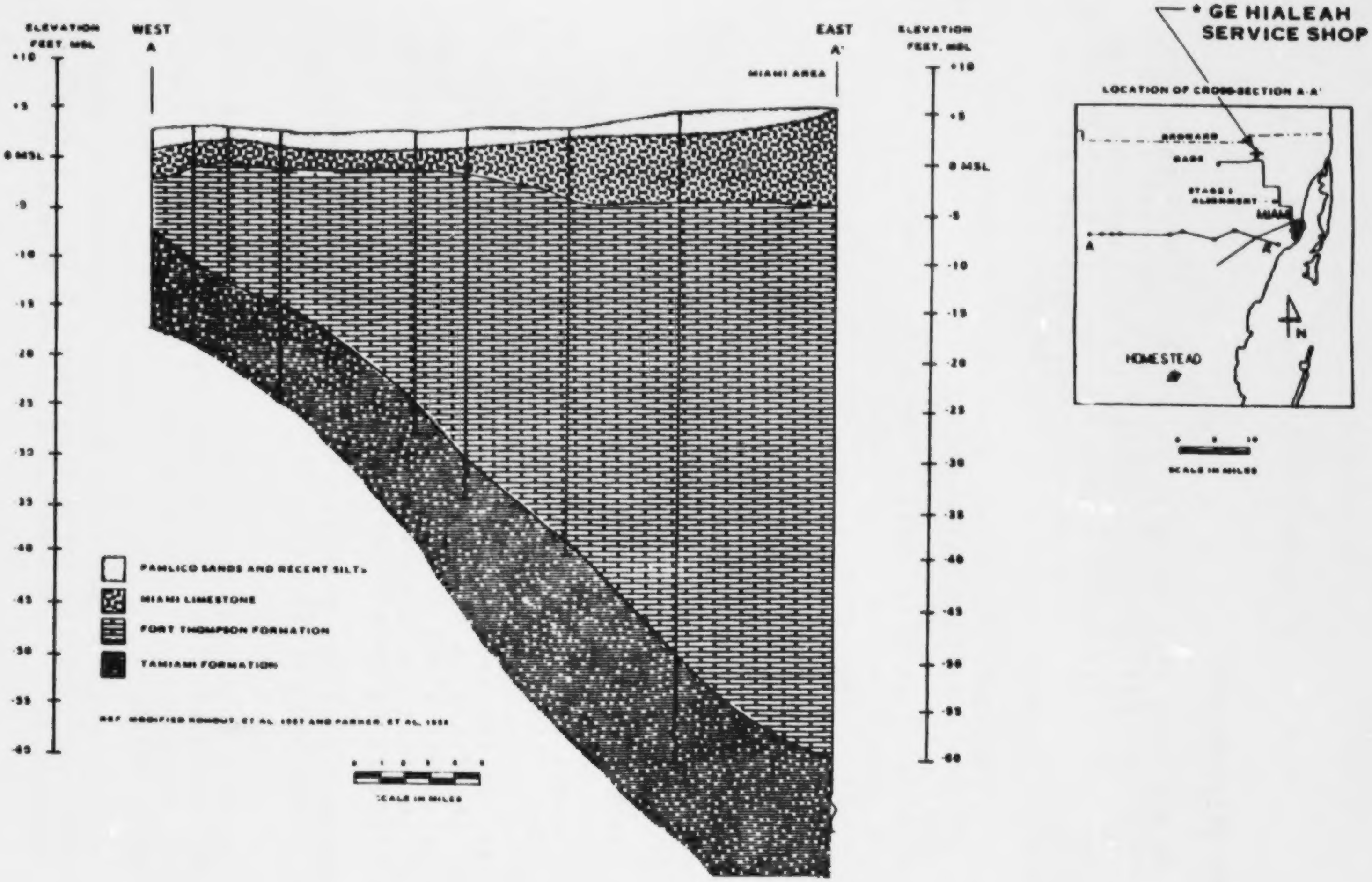
The following information was provided from reports prepared for GE. The east-west geologic section through Dade County (see Fig. 8) shows that the upper stratum is unconsolidated quartz sand, typically about 5 ft thick. The Miami limestone, which immediately underlies the surface sand stratum, is typically 5 to 10 ft thick in this area. The Miami limestone in this portion of Dade County has been found to be generally soft, porous and slightly oolitic. It character- istically contains solution channels, up to about 1 in. in diameter.

Uncemented fine quartz-sand immediately underlies the Miami limestone. The uncemented sand zones have been encountered in thicknesses of about 30 to 50 ft. Below this, the Fort Thompson formation includes zones of sandstone, limestone, and unconsolidated sands. The Fort Thompson formation is wedge-shaped in cross section, having its maximum thickness along the coast and pinching out along the western boundary of Dade County. The base of the Biscayne Aquifer is a relatively impermeable greenish-marl of the Tamiami formation. Fig. 8 shows that, in the east-west direction through the Hialeah vicinity, the Biscayne Aquifer is wedge-shaped, having its maximum thickness along the coast (maximum thickness of about 200 ft in the Fort Lauderdale area) and wedging out along the western boundary of Dade County.

Permeability of the Biscayne Aquifer probably averages between 40,000 and 70,000 gal/d/ft^2. These values correspond to 2.4-3.3 cm/s.

The general groundwater gradient in and around north Dade County is relatively flat and slopes toward the east and southeast. This natural slope is locally modified by canals and water-supply wells.

The average yearly lowest-and-highest groundwater-levels in the service shop vicinity range from about 4 to 7 ft below grade. Measurements performed for GE showed a relatively flat


ELEVATION FEET, MSL
+10
+5
0 MSL
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
WEST
A
EAST
A'
MIAMI AREA
PAMLICO SANDS AND RECENT SILTS
MIAMI LIMESTONE
FORT THOMPSON FORMATION
TAMIAMI FORMATION
0 1 2 3 4 5
SCALE IN MILES
* GE HIALEAH SERVICE SHOP
LOCATION OF CROSS-SECTION A-A'
BROWARD
DADE
STAGE I ALIGNMENT
MIAMI
A
A'
HOMESTEAD
N
0 5 10
SCALE IN MILES

REF. MODIFIED [illegible], ET AL. [illegible] AND PARKER, ET AL. [illegible]

Figure 8. Miami area regional geological cross-section.

water table, without a discernible gradient. It is possible that groundwater could flow, under certain conditions, in almost any direction.

Permeabilities on the order of 2.4 cm/s reflect the influence of interconnected cavernous zones in the limestone. Permeabilities in surface sand stratum and unconsolidated Fort Thompson sands would most likely be in the range of 10^{-3} to 10^{-2} cm/s.

5.2 WASTE CHARACTERISTICS

Bborings and soil analyses in a five-phase study were performed by GE and reported between July 6, 1984, and April 10, 1986. During this period, 536 soil samples were analyzed for PCBs. In addition, they analyzed water samples from each of the onsite and offsite monitoring wells for PCBs and volatile organic compounds (VOCs). Results from onsite well-monitoring data showed some low levels of VOCs in most of the wells. Therefore, a few untreated-soil samples were analyzed for VOCs.

The principal site contamination is considered to be from PCBs, although some VOCs were measured near a drainage drum next to the east wall of the service shop. Appendix H provides PCB-concentration profiles within the GE property line.

PCBs in the subsurface are primarily: on the east side of the site in the area of the shop building; under the southeastern portion of the low-bay shop building; and south of the low bay shop building. Some shallow concentrations are indicated west of the shop building. The maximum PCB concentration is 5,639 mg/kg at a 1-ft depth in the northeast corner of the site. Concentrations above 100 mg/kg occur infrequently below the 8-ft depth level. The maximum concentrations in each of the test sectors, as measured by LE, were 2,150 and 435 mg/kg. EPA did not measure such high values in the SITE Project pretreatment sampling of the test sectors. PCBs found at the GE site are among the variety of highly chlorinated biphenyls.

PCBs are pale-yellow viscous fluids with a mild hydrocarbon odor. In September 1977 the National Institute for Occupational Safety and Health (NIOSH) classified PCBs as potentially hazardous substances . The Immediately Dangerous to Life or Health (IDLH) level -- the maximum concentration at which 30-min exposure will not result in any health impairment -- is 5 mg/m^3. PCBs are considered carcinogenic.

SECTION 6

DEMONSTRATION PROCEDURES

6.1 SITE AND WASTE PREPARATION

EPA's principal roles for the onsite demonstration were to conduct field sampling -- which included soil borings before and after the test sector remediation -- and to make observations of the operations. However, EPA did not perform the site preparation for the SITE Project demonstration because GE had prepared the entire site as part of their site remediation obligation to Metropolitan Dade County Environmental Resources Management (MCDERM). GE provided utilities and building facilities from the existing plant for the test. The sampling contractor was able to use the plant's utilities, except for sanitary and communication facilities, which EPA provided during the two sampling periods.

6.2 OPERATIONAL PLAN

Geo-Con, Inc. personnel injected and mixed the HWT-20 additive with the soil as a slurry. The additive was delivered in dry powder form to the site in trucks, and conveyed by air to a storage bin. The slurry was prepared in a blending plant, as described in Section 4.2, which was set up in the high-bay shop building.

IWT, the HWT-20 supplier, provided a proposed mix design for the treatment slurry prior to the start of work. The mix design provided the amounts of additive, water, and other ingredients required in each batch of treatment slurry.

During batching, the quality control inspector, provided by GE, spot checked and documented the correct amount of ingredients, HWT-20 additive and sodium silicate, in each batch. The blending plant had the volume- and weight-measuring capability necessary to permit this documentation. EPA collected similar data concurrently.

Prior to the start of work, Geo-Con made calculations to determine the volume of treatment slurry required to be injected at each location in order to provide the planned ratio of HWT-20-weight to dry-soil-weight of 0.15. During auger withdrawal at each penetration location, the quality control inspector observed and documented that the required quantity of slurry has been injected. The quality control inspector also took detailed measurements of the location of each column in Sector B.

Two test sectors on the site were used for the in situ treatment. The locations selected by GE and IWT were high in

PCBs; values up to 2,000 mg/kg were expected. The planned depths of in situ treatment in each area were 1.6 ft (0.5 m) deeper than the maximum depth to which PCB concentrations greater than 1.0 mg/kg had been measured. This provided for a treatment depth in Sector B of 18.0 ft, and 14.0 ft in Sector C. This was part of the criteria established by the local regulatory authorities.

The drilling pattern consisted of alternate and overlapping primary and secondary strokes. All the primary strokes were performed first in each sector before the secondary strokes were performed. In test Sector B, the secondary-stroke feedrates were reduced in proportion to the untreated area remaining -- about 75% of that of the primary stroke. This variation was at the request of GE, to determine if the use of less additive in Sector B would have an impact on the results. In test Sector C, both the primary and secondary strokes received the same quantity of HWT-20. Sodium silicate was added to form a fast-setting zone below both test sector areas to help contain the soil-slurry additive mix, which was expected to be of lower permeability than the treated soil without sodium silicate.

The actual location of each treated soil column in Sector B was measured and compared to the targeted locations. In Sector C column locations were not measured.

6.3 SAMPLING AND ANALYSIS ACTIVITIES

6.3.1 Sampling Locations

EPA performed soil sampling two weeks before, and five weeks after, test sector remediation. The sampling locations were selected primarily to obtain information on the following evaluation criteria:

1. Mobility of the PCBs around areas of high concentration or hot spots. Mobility of VOCs and heavy metals, if detected from spot sampling.

2. Uniformity of the in situ solidified soil mass.

    (a) Impact of sodium silicate on producing a more impermeable boundary layer, compared to the body of the solidified mass.

    (b) Soil properties determined at depths above and below the water table in order to ascertain the impact of moisture content.

    (c) Sampling in unconsolidated sand and limestone layers, to indicate the process impact of the process on different soils.

Diagrams providing the planned sampling locations are shown in Figs. 9, 10 and 11. Samples were taken at approximately the same locations before and after the remediation.

One location in each sector was anticipated to be a hot spot. At this location, five samples were taken at a selected depth below the surface -- 1-2 ft in Sector B and 7-8 ft in Sector C. A central sample was taken, along with four additional samples about 18 in. away along a circumferential arc.

To evaluate uniformity of the in situ solidification, samples were taken at three or four levels: from the top layer of unconsolidated sand, the limestone layer, and the lower unconsolidated sand layer. For two of the locations in Sector B, a fourth sample was taken in the boundary layer at the bottom of the solidified mass. The sample depths with respect to the surface were as follows:

Top unconsolidated sand	1-2 ft
Limestone	7-8 ft
Lower unconsolidated sand	11-12 ft
Boundary layer - Sector B only	16-17 ft

In Sector C, with a 14-ft treatment depth, the third (11-12 ft depth) sample was in the boundary layer. The sampling logs taken during pretreatment and posttreatment sampling are in Appendix G.

6.3.1.1 Determine PCB Mobility--

For the two PCB hot spots, the posttreatment samples were taken at the treatment-auger injection center, with four more samples taken up to 18 in. away within the diameter of a treatment column. Not only did these four peripheral samples provide additional samples for leaching tests of highly contaminated soil, but they also indicated the treated soil uniformity, by sampling at locations of column overlap. Section 5.5.4 describes the analyses in detail.

6.3.1.2 Determine In Situ Solidification Uniformity--

Solidified hazardous wastes are multi-phased materials whose microstructure controls their leaching behavior and long-term stability. Since cement setting reactions are complex, it was important to characterize the microstructure to identify potential durability problems.

Small-scale non-homogeneities or porosity can lead to degradation of mechanical properties over time and possibly allow the release of contaminants. Treated soils were characterized by using scanning electron microscopy (SEM) and X-ray diffraction. These techniques provided information about porosity, uniformity, degree of mixing and mineral content of the cured material.

Unconfined compressive strength, a test to be performed on all treated soil samples, is a measure of the homogeneity and

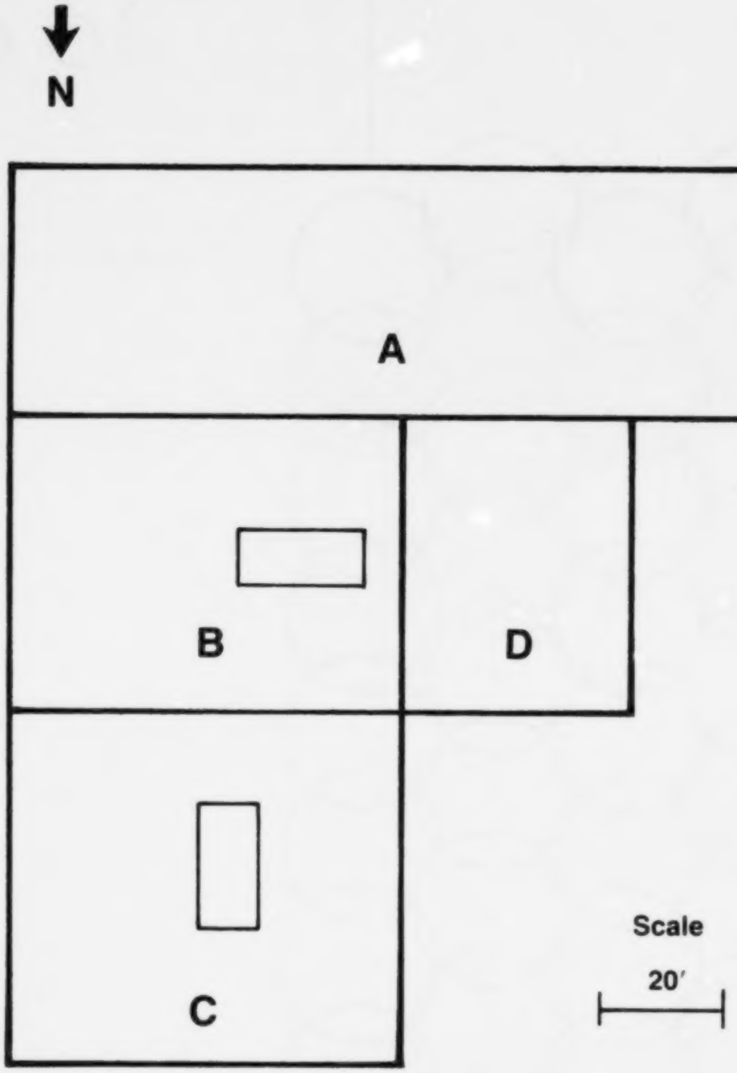

N
A
B
D
C
Scale
20′

Figure 9. Sampling sector locations.

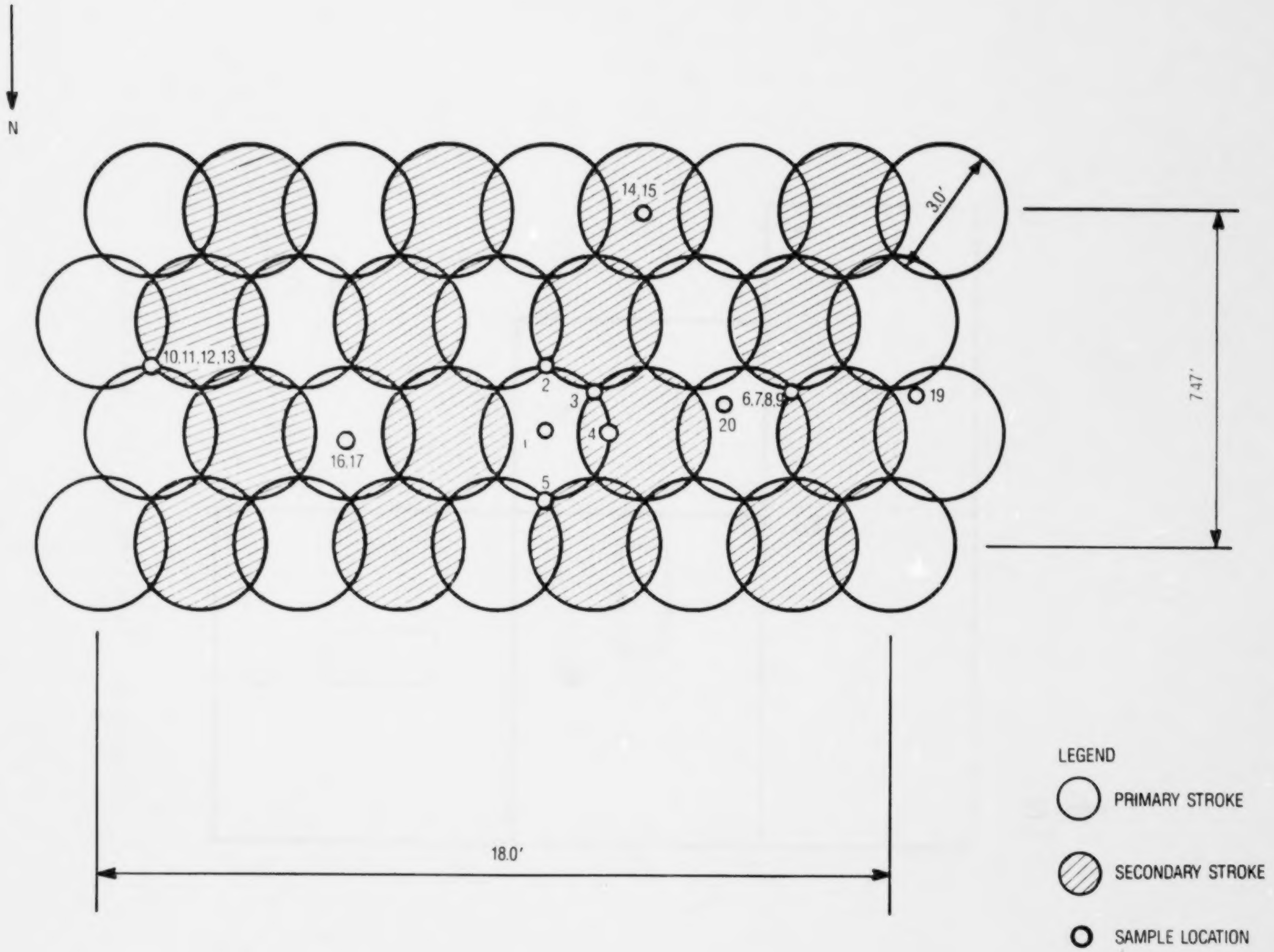

N
14,15
3.0'
10,11,12,13
2
3
6,7,8,9
19
20
1
4
16,17
5
7.47'
18.0'
LEGEND
PRIMARY STROKE
SECONDARY STROKE
SAMPLE LOCATION

Figure 10. Sampling locations - Sector B.

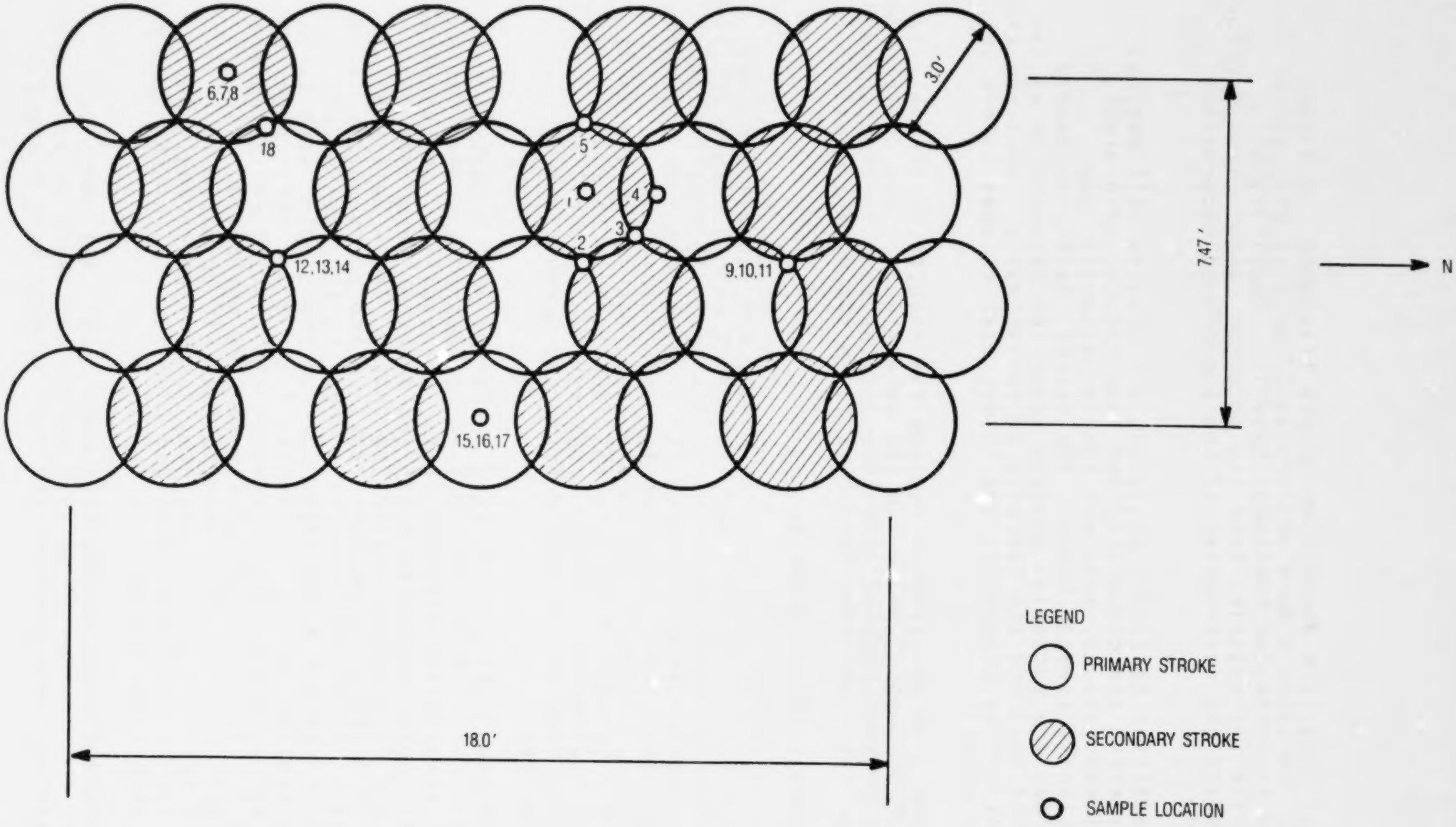

3.0'
6,7,8
18
5
1
4
3
2
12,13,14
9,10,11
15,16,17
7.47'
N
18.0'
LEGEND
PRIMARY STROKE
SECONDARY STROKE
SAMPLE LOCATION

Figure 11. Sampling locations - Sector C.

potential long-term durability of the treatment. A higher strength indicates a more uniform soil/additive mix, which provides an increased treatment benefit. Inability to incorporate the organics into the physical cement microstructure could retard the development of the unconfined compressive strength.

In addition to sample analysis, all treated soil borings were inspected and documented for fine cracks, void areas, material consistency, apparent sample integrity, and insufficiently treated areas. Any cracks, voids, or poorly mixed areas are potential problem areas for degradation of the solidified mass and the leaching of contaminants. However, this is a qualitative judgement, and it may take decades before any problems exist.

It was also of value to analyze the results of the in situ mixing of soil above and below the water table. Any differences existing between treated limestone and the sand layers (above and below the limestone) were checked in the data analysis.

6.3.2 Sample Recovery Procedures

Unconsolidated soil (pretreatment), and consolidated soil (posttreatment), samplings were performed with a rotary drilling rig. Untreated soil samples were obtained with a split spoon sampler. Samples were collected for chemical analyses, leaching tests, moisture level measurements, and grain size measurements. Separate VOC samples were taken from the split spoon, refrigerated in 40-mL vials, and sent to the laboratory on the day collected. Shelby tubes were used to collect undisturbed samples for bulk density and permeability determinations.

Solidified soil samples were extracted with a core barrel assembly. Core samples of 2.875-in. diameter were used for bulk density, compressive strength tests, permeability, and chemical analyses. Core samples of 2.125-in. diameter were used for wet/dry and freeze/thaw weathering tests. These multiple samples of different diameters required the boring of at least two holes at each sample location. Due to the loss of the 2.875-in. corer for a few days, some of the samples were taken with the smaller corer. See Tables 7 and 8 for definitions of samples using only 2.125-in. corer. Air cooling of the corer was used for the first 40% of the samples collected. The cooling procedure was then changed from air to water to eliminate the soil dusting that existed during coring. See Table 7 for samples taken with air cooling. All of the Sector C samples were water-cooled.

Standard diamond coring-bits were used. All sampling equipment was cleaned after each sample was taken to avoid cross contamination. All sediment and rock samples were wrapped in aluminum foil, placed in glass jars, closed with a custody seal, placed in zip-loc bags, then in cans packed with vermiculite, and stored with ice packs in coolers closed with a custody seal.

Two duplicate sample sets were taken for each test sector (one for each ten samples as required by the Quality Assurance Project Plan). Duplicate samples required additional borings, which were located as close as possible to the original samples. They were analyzed for PCBs, all physical properties, and leach test data. For each soil boring, logsheets describing the core samples were prepared. For each boring, photographs of the cores were taken to complement the logsheet descriptions.

6.3.3 Analytical Procedures

Soil samples were taken before and after the site remediation. The purpose of the pretreatment soil analyses was to characterize the soil and determine the contaminant levels at specific locations; these locations also were tested after the remediation, so that a direct comparison of the physical and chemical properties before and after remediation could be made. However, since the treatment process involves a high degree of soil mixing, it is difficult to obtain comparable samples from the same location before and after treatment. Table 2 presents the analyses performed on the pretreatment soil samples, along with procedures used.

The posttreatment core samples were taken at approximately the same locations as the pretreatment samples. Their purpose was to evaluate the changes in the soil properties and the ability of the contaminants to migrate from the treated soil.

Table 3 gives the analyses performed on the core samples, taken five weeks after the two test sectors were remediated, along with procedures used.

In addition, formulation tests were performed as a baseline for the demonstration in the laboratory of the analysis contractor. PCB-contaminated soil and cement (without HWT-20) were blended at the same dosage rate as the IWT additive. In addition, clean soil from the site and cement also were formulated. Analyses performed were for moisture, bulk density, compressive strength, permeability, and the Toxic Characteristic Leaching Procedure (TCLP) test for PCBs.

Pretreatment analyses provided a range of important information. The grain size, pH, moisture, and bulk density define basic soil characteristics. Oil-and-grease and total-organic-carbon are both measures of organics in the soil, which may interfere with the stabilization/solidification process. Organics, usually above 10 wt%, interfere with many cement-based fixation processes.

TABLE 2. PRETREATMENT ANALYSES

Test type	No. of samples	Procedure[a,b]
Grain size	34	ASTM D 422-63 (reapproved in 1972)
pH	34	SW 9045
Moisture	34	ASTM D 2216-80
Bulk density	34	American Society of Agronomy - Methods of Soil Analysis - p.375
Oil and grease	34	Standard Method 503D - American Public Health Assn., 16th Edition
Total organic carbon	34	Walkley-Black
Total metals (Sb, As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Th, Zn)	12 (e)	Digestion and Atomic Absorption - See Table 5.1 and Appendix A of QAPP, Section 6.0
Total PCBs in soil	34	SW 846 Method 8080
Permeability	34	American Soc. of Agronomy - Methods of Soil Analysis (in conjunction with bulk density)
Leaching	34	EP TCLP - Federal Register 11/7/86, Vol. 51, No. 216, Appendix 1, Part 268; SW 846 Method 8080
Volatile organics in soil (32 on NPDES list)	8(c)	SW 8240
Microstructural analyses(a)	6	Scanning Electron Microscope and X-ray Diffraction
Formulation test (e)	6	(f)

(a) Where analyses showed significant metals or VOCs, leachate analyses for those components were added.
(b) All procedures are defined in more detail in Section 6.0 of the QAPP.
(c) Sample locations B-1, 6, 7, 8; C-1, 9, 10, 11.
(d) Soil was taken from locations B-1 and C-1 for laboratory formulation tests. Clean soil was taken from the site.
(e) Soil was taken from locations B-1, 6, 7, 8, 21, 22 and C-1, 9, 10, 11, 12, 13.
(f) See Section 5.4 for analyses to be performed.

TABLE 3. POSTTREATMENT ANALYSES

Test type	No. of samples	Procedure[a]
Moisture	43	Test Methods for Solidified Waste Characterization (TMSWC)-Section 4
Bulk density	43	TMSWC - Section 2
Unconfined compressive strength	45	ASTM D 2166-66 (1981)
Wet/Dry weathering test	41	TMSWC - Section 12
Freeze/Thaw weathering test	38	TMSWC - Section 11
Unconfined compressive strength after weathering tests (test specimen and control)	58[b]	ASTM D 2166-66 (1981)
Permeability after weathering tests	20[b]	Falling Head TMSWC - Section 13
Total PCBs in soil	42	SW 846 Method 8080
Permeability	41	Falling Head - TMSWC- Section 13
Leaching	42	EP TCLP - Federal Register 11/7/86, Vol. 51, No. 216, Appendix 1, Part 268; Method 8080
	6[a]	MCC-1P-Static Leach Test (Materials Characterization Center); Method 8080
	6[a]	ANS 16.1-Multiple Extraction (American Nuclear Society); Method 8080
Microstructural analyses	40	Scanning Electron Microscope and X-ray Diffraction

(a) Samples from B-6 and B-7 were analyzed for both tests with site water and deionized water. In Sector C, ANS 16.1 was performed on samples from C-2,4, and MCC-1P was performed on samples from C-1,3 using site water.

(b) For approximately half the weathering samples, UCS and permeabilities were performed.

Analyses for PCBs, volatile organics, and priority pollutant metals defined the contaminants in the soils and indicated those contaminants to include in leaching tests. The metals content was measured at only three sampling points in each sector, since metals were not expected to be present in significant quantities. At one of these three points, samples were taken at three different depths; at another two depths; and at the third, a sample was taken at just one depth. VOC content was measured at only two locations in each sector--one at each sampling depth, plus one at the 1-2 ft level in Sector B and at the 7-8 ft level in Sector C--since VOCs also were not expected to be present in the soil. The permeability and leachability tests provide data on two properties related to the mechanism of contaminant mobility that should change dramatically with the soil treatment.

The posttreatment analyses characterized the treated soil. The moisture and bulk density tests provided information on soil properties and changes in soil volume as a result of the treatment. The unconfined compressive strength indicated a measure of the product mix uniformity and potential soil durability. The wet/dry and freeze/thaw weathering tests provided indications of life expectancy of the solidified material through moisture and temperature cycles. Unconfined compressive strength tests were performed on the weathered test specimens to determine if there was any loss of strength. Some permeabilities of the weathered samples also were performed.

Permeability and leachability are measures of the likely mobility of the contaminants into groundwater. A comparison of treated and untreated soil was made. Two special leach tests were used to attempt to simulate the leaching of the material as it would occur in the ground. They were MCC-1P, Static Leach Test, and ANS 16.1, Multiple Extraction Leach Test, both developed for monitoring low-level radioactive wastes for the nuclear industry, but modified for use with hazardous wastes. These tests were performed on samples from each of the two PCB and VOC hot spots, using site water and deionized water in Sector B and the PCB hot spot in Sector C. The standard TCLP test requires grinding of the solidified mass.

6.3.4 Range of Testing

The range of variables tested to evaluate the technology was restricted, since the Demonstration Test was part of the site remediation process. Therefore, existing operating conditions had to be used. However, some variability did exist at the Hialeah site that provided valuable information. These variables were:

1. PCB contamination level ranged from 1 to 950 mg/kg.
2. The moisture in the soil above the water table (5-7 ft below the surface) averaged about 5.5 wt% and in the soil below the water table averaged about 18 wt%.

3. Soils included unconsolidated sand as well as soft, porous limestone.
4. Small variations in total organic carbon.
5. Ability to mix the additive with soil at various depths -- to a depth of almost 18 ft.
6. Impact on permeability, solidification integrity, and other soil properties of adding sodium silicate to the additive for the bottom 3 ft in each sector.

6.4 SCREENING ANALYSIS

Prior to the demonstration, EPA performed tests on samples previously prepared for GE as a preliminary evaluation of the technology before proceeding with the demonstration (see Table 4). Treated soil from the GE site was obtained from GE along with the following information:

Designation	PCB Concentration (ppm)(c)	HWT-20 Additive rate (lbs/lb dry soil)	Moisture condition(a)	Formulation date(b)
SL-21	1,130	0.15	Above	12/86
SL-24	5,628	0.20	Below	12/86
TG-17	5,628	0.12	Below	8/86

(a) Simulating above, or below, water table.
(b) The 12/86 samples were prepared by mixing soil with a slurry additive, while for the 8/86 sample, the additive was mixed with the dry soil, then water was added.
(c) Values reported by GE.

TABLE 4. SCREENING SAMPLES RESULTS

Parameter	SL-21	SL-24	TG-17
Moisture, wt%	9.84	16.09	8.59
Bulk density, g/mL	1.97	1.67	1.86
Permeability, 10^{-8} cm/s	3.6	4.2	0.44
Unconfined compressive strength, psi	876	418	1185
Leachability - PCB concentration			
PCB in solid being leached, mg/kg	4,100	4,900	5,700
TCLP, µg/L	ND	ND	ND
MCC-1P, µg/L	ND	ND	ND

ND = Not detected. Detection limit, 1 µg/L.

EPA results summarized in Table 4 show low permeability, approximately 10^{-8} cm/s; high unconfined compressive strengths, 418 to 1,185 psi; and immobilization of the PCBs.

In addition, a microstructural analysis was performed. The samples examined were porous and incompletely hydrated. These results indicated a potential for durability problems. These results will be compared to those of the demonstration in Section 7.

6.5 PHYSICAL TESTS

The physical tests described below were used to analyze the soil and leachate samples during this SITE project.

ASTM D 422-63: Grain Size Analysis

This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 microns (retained on the No. 200 sieve) was determined by sieving, while the distribution of particle sizes smaller than 75 microns was determined by a sedimentation process using a hydrometer to secure the necessary data.

EPA-600/4-79-020: Methods for Chemical Analysis of Water and Wastes

EPA Method 600 was used to determine the water content of untreated soil samples. Moisture was determined by measuring the mass of water removed by drying the sample to a constant mass at 103^{o}-105^{o}C.

TMSWC-4: Water Content (Moisture) - Solid Cores

A 50-g sample was ground to pass an ASTM No. 10 sieve. The mass of the sample was measured before and after drying in an oven maintained at 60^{o} $\pm 3^{o}$C. The dry weight must be a constant weight (mass change of less than 0.03 g in 4 h). The wet sample mass was divided into the difference of the wet sample mass minus the dry sample mass.

Bulk Density

Bulk density was determined in the demonstration using the Core Method described in Methods of Soil Analysis, American Society of Agronomy, 1965. The mass of the samples was calculated by difference, using a top-loading balance. The dimensions of the specimen (cube or cylinder) were measured using a 30-cm ruler having a precision of ±1 mm. The bulk density was calculated by dividing the volume into the mass.

ASTM D 2434: Permeability Coefficient-Constant Head

Permeability coefficient was determined by a constant head method for determining the laminar flow rate of water through granular soils. This procedure was limited to disturbed granular soils containing not more than 10% soil passing the 75 μm (No. 200 sieve). For the demonstration measurements were made on minimally disturbed soil samples collected in Shelby Tubes (when the bulk density samples were taken.)

TMSWC-13: Permeability Coefficient-Falling Head-Solid Cores

This test was carried out in the demonstration on the solidified 7- and 28-day core samples. A cylindrical sample 7.62x7.62 cm was used. Permeability was determined using a triaxial cell measuring changes of water volume over time under controlled conditions of temperature and pressure.

ASTM D-1633: Unconfined Compressive Strength Test

This test method covers the determination of the unconfined compressive strength of molded soil-cement cylinders using strain-controlled application of the axial load.

TMSWC-12: Wet/Dry Weathering Test

This test, which provides indications of short-term durability of the solidified mass, was performed in the demonstration using two 4.5x7.4-cm cylindrical core specimens of solidified wastes. It was carried out in conjunction with TMSWC Method 4.0, Water Content. One of the specimens was used as the test specimen, the other as the control.

Two solidified test samples were compared by weight difference. One sample, the control, was placed in a humidity chamber, and the other was dried in an oven at 60^{o}-65^{o}C for 24 ±1 h. The sample specimen then was cooled in a desiccator, and 230 mL of water was added to each sample. The sample and control then were placed in the humidity chamber for 24 h. This was repeated 11 times. The weight loss of test specimen and control and the relative weight loss were then calculated for each cycle.

TMSWC-11: Freeze/Thaw Test

This test, which provides information on short-term durability of the solidified mass, is a more severe cycling than would occur in nature and was performed using two 4.5x7.4-cm cylindrical core specimens of solidified waste. The test was carried out in conjunction with the water content determination. One of the two specimens was used as a control. The test specimen was placed in a freezer at -20 $\pm 3^{o}$C for 24 ±1 h. Water was then added to the frozen specimen and control and maintained at 22 $\pm 3^{o}$C for 24 ±1 h.

The process was repeated 11 additional times, with relative weight loss calculated after each cycle.

Modified Bulk Density

Eight untreated soil samples, which could not be collected in Shelby Tubes, were analyzed as described in the following paragraphs.

Non-pourable samples were placed into a tube of known dimensions and vibrated until a light film of water surfaced, at which time weight and height measurements were taken. The density was calculated using the core method.

Pourable samples were poured into a 100-ml graduated cylinder of known weight. The graduate containing the sample was weighed. The density was calculated using the formula,

$$D = W/V$$

where D is the density, W is the weight of the sample, and V is the volume.

6.6 CHEMICAL TESTS

The chemical tests and definitions of the contaminants as described below were used to analyze the soil and leachate samples during this SITE project.

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls are a group of related isomers of chlorinated organic compounds characterized by having 1 to 10 chlorine atoms substituted on the biphenyl group.

Priority Pollutant Metals

Thirteen priority pollutant metals have been specified to be of particular environmental concern by the U.S. Environmental Protection Agency. The metals are: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Four of these metals were found in measurable concentrations in contaminated soils from the Hialeah site -- chromium, copper, lead, and zinc. To conserve resources, only the four metals found at the site were analyzed for in many of the samples tested.

Volatile Organic Compounds (VOCs)

Volatile organic compounds were determined by purging volatiles from the samples tested. Compounds measured at Hialeah were xylenes, chlorobenzene, and ethyl benzene.

Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP was designed to determine the mobility of both organic and inorganic contaminants present in liquid, solid, and multiphase wastes. For wastes comprised of solids, the particle size of the waste was reduced and analytes are extracted for 18 hours with an acetic acid solution. Two liters of extractant (fluid no. 2) were used for 100 g of solid. The extract was then separated from the solid phase and analyzed for PCBs, Priority Pollutant Metals, and VOCs. This procedure was developed to measure a wider variety of contaminants, including volatile organics, than is measured by EP Toxicity.

MCC-1P: Modified Static Leach Test

The static leach test establishes the maximum concentrations of elements in a quasi-static groundwater regime that has been in contact with a stabilized waste. The samples are kept as solid cores to simulate an in situ condition. For the SITE demonstration, cylinders cured for at least 28 days were used and were taken from the core barrel drilling. Four test specimens for each test were leached with organic-free ultra pure water, at 40^{o}C, for four varying time periods up to 28 days. Leachates then were analyzed for all contaminants.

ANS 16.1: Leach Test

The intact samples for the demonstration, cut from the solid cores, were leached, using ultra pure water. The sample specimen was placed in fresh leachates at five different time intervals, with the total leaching time being 28 days. (This differs from the TCLP and the MCC-1P, where each of four specimens for MCC-1P is placed in water once and held there for varying time frames up to 28 days.) Therefore, five leachates were analyzed for the organic and inorganic contaminants.

SW846 Method 9045: Soil pH

The pH of a sample was determined in the demonstration electrometrically using either a glass electrode in combination with a reference potential or a combination electrode. In soil samples, pH was determined by preparing a slurry, using equal volumes of soil and deionized water and measuring the pH of the decanted liquid.

APHA 503D: Oil and Grease

Method 503D is a modification of the Soxhlet extraction method, which is suitable for sludges. Magnesium sulfate monohydrate was combined with the sludge to remove water (as $MgSO_4 \times 7H_2O$). After drying, the oil and grease was extracted in a Soxhlet apparatus with trichlorofluoromethane and after solvent evaporation was measured gravimetrically.

Total Organic Carbon - Walkley-Black Method

Oxidizable matter in a soil sample was oxidized by the chromate ion ($Cr_2O_7^{-2}$), and the reaction was facilitated by the heat generated when two volumes of sulfuric acid were mixed with one volume of potassium dichromate ($K_2Cr_2O_7$). The excess chromate was determined by titration with ferrous sulfate, and the quantity of substances oxidized was calculated from the amount of $Cr_2O_7^{-2}$ reduced.

SW846 Method 3510: Liquid-Liquid Extraction

Method 3510 is a procedure for isolating organic compounds from aqueous samples. A measured volume of sample was serially extracted with methylene chloride using a separatory funnel. The extract was dried, concentrated, and, as necessary, exchanged into another solvent compatible with the cleanup or determinative step to be used.

SW846 Method 5030: Purge-and-Trap

Method 5030 describes sample preparation and extraction for the analysis of volatile organics by a purge-and-trap procedure. An inert gas was bubbled through the aqueous sample at ambient temperature, and the volatile compounds were transferred from the aqueous to the vapor phase. The vapor was swept through a sorbent column where the volatile components were adsorbed. After purging was completed, the sorbent column was heated and back-flushed with inert gas to desorb the components onto a gas chromatographic column.

EPA Method 8240: Gas Chromatography/Mass Spectrometry (GC/MS for Volatile Organics

Method 8240 is a GC/MS procedure used to determine the concentration of volatile organic compounds in a variety of solid waste matrices. Method 8240 can be used to quantify most volatile organic compounds that have boiling points below 200°C and that are insoluble or slightly soluble in water. These include low-molecular-weight halogenated hydrocarbons, aromatics, nitriles, ketones, acetates, acrylates, ethers, and sulfides. The volatile compounds were introduced into the GC by a method similar to the purge-and-trap method; detection was by a mass spectrometer.

SW846 Method 8080: GC/ECD for PCBs

Method 8080 was for the gas chromatographic analysis of PCBs. Prior to analysis, samples were subject to appropriate extraction procedures. Samples were injected into the GC using the solvent flush technique. Compounds in the GC effluent were detected by an electron capture detector (ECD).

SW846 Method 680: GC/MS for PCBs

Method 680 is used to determine pesticides and polychlorinated biphenyls (PCBs) in waters, soils, and sediments by gas chromatography/mass spectrometry (GC/MS). It is applicable to samples containing single congeners or to samples containing complex mixtures, such as Aroclors. Polychlorinated biphenyls (PCBs) are identified and measured as isomer groups by levels of chlorination.

SW846 Method 3050: Acid Digestion for Metals

Method 3050 is an acid digestion procedure used to prepare sediments, sludges, and soil samples for analysis by flame or furnace Atomic Absorption (AA) spectroscopy. A representative sample is digested with HNO_3 and H_2O_2. The digestate is then refluxed with either HNO_3 or HCl.

SW846 Method 3010: Acid Digestion for Metals

Method 3010 is a digestion procedure used to prepare samples for analysis by flame Atomic Absorption. The sample was mixed with HNO_3 and allowed to reflux in a covered Griffin beaker, followed by refluxing with HCl.

SW846 Methods 7060/7740: Furnace AA

Methods 7060 and 7740 are graphite furnace atomic absorption techniques approved for determination of arsenic and selenium. Following sample digestion, an aliquot of sample was placed in a graphite tube in the furnace, evaporated to dryness, charred, and atomized. The metal atoms to be measured were placed in the light path of an atomic spectrophotometer.

SW846 Methods 7470/7471: Mercury by Cold Vapor Atomic Absorption (CVAA)

Method 7470 is a cold-vapor atomic-absorption procedure for determining the concentration of mercury in mobility-procedure extractions. Method 7471 is prescribed for solid and sludge-type wastes. Sample preparation is specified in each method. Following dissolution, mercury in the sample was reduced to the elemental state and aerated from solution in a closed system. The mercury vapor passed through a cell positioned in the light path of an atomic absorption spectrophotometer.

SW846 Methods 7040/7090/7130/7190/7210/7420/7520/7760/7840/7950

These methods are used to analyze antimony, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, and zinc. The method of analysis is direct aspiration atomic absorption spectroscopy, where a sample is aspirated and atomized in a flame. A light beam from a cathode lamp whose cathode was made of the element to be determined was directed through the flame into a monochrometer and onto a detector that measured the amount of light absorbed. Since the wavelength of the light beam is characteristic of only the metal being determined, the light energy absorbed by the flame is a measure of the concentration in the sample.

SECTION 7

FIELD ACTIVITIES

7.1 OPERATIONAL HISTORY

The sampling contractor arrived at the electric service shop on March 17, 1988, to start preparations for the pretreatment sampling. This included the following:

- Staking out the two test sectors
- Locating and flagging each sample location
- Constructing an equipment decontamination area
- Setting up the sample preparation area
- Providing for personnel facilities - clean office, office furniture, sanitary facilities
- Setting up health and safety facilities
- Purchasing necessary materials for decontamination, health and safety, and sample shipping.

The drilling crew arrived on site on Monday, March 21, and the first samples were collected the next day. From March 22-26, 17 sets of samples were taken from each test sector and sent to the laboratory for analyses.

Geo-Con, Inc. arrived on site on March 28, 1988, and spent two weeks setting up their equipment. This included the mixing plant, crane with drilling auger, a template the size of each test sector for locating each column of treated soil, control instrumentation, and decontamination facilities. The equipment then was tested by treating a preliminary column outside the test sectors. A calibration curve of slurry concentration versus solids concentration was prepared for the HWT-20 additive.

The remediation of the two sectors, which required the production of 36 columns of treated soil in each, started on April 11. Each sector took three days to treat, and the remediation was completed on April 16. Sector B was treated first. For Sector B only, GE's quality assurance officer took measurements to determine the actual location of each column of treated soil (see Fig. 12). Geo-Con, GE, and EPA recorded operational data and observations separately.

The operations started with the preparation of the additive slurry batch. A known volume of water was added to the slurry preparation tank, and then a predetermined quantity of HWT-20 was added by a calibrated rotary valve. When a uniform slurry was attained, usually in less than five minutes, a sample was taken and the specific gravity was measured on a mud balance. The target value was 1.[illegible] g/mL for a 4/3 weight ratio of additive to water. If the value deviated, either water or additive was injected to

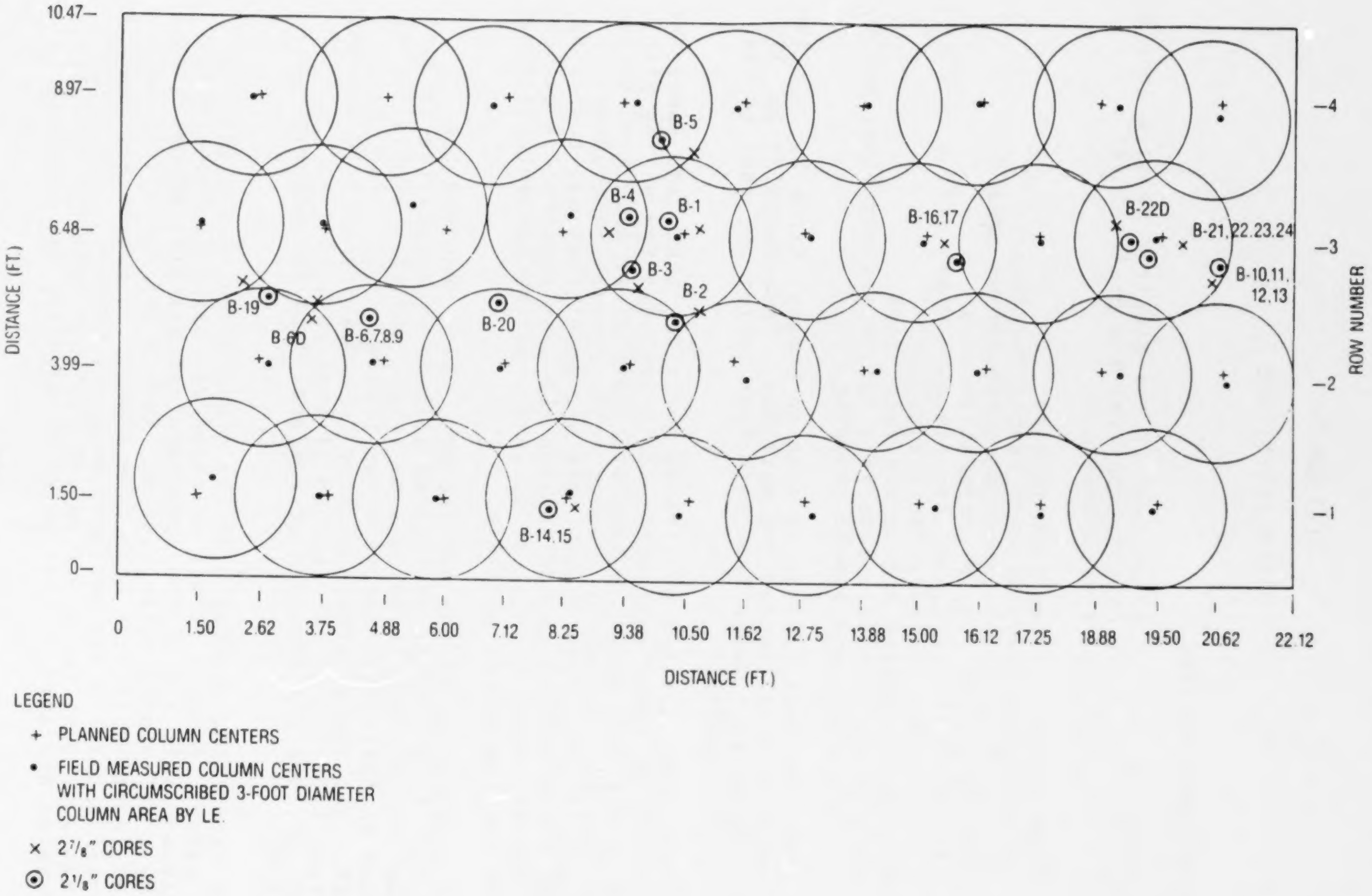

10.47
8.97
6.48
3.99
1.50
0
DISTANCE (FT.)
0
1.50
2.62
3.75
4.88
6.00
7.12
8.25
9.38
10.50
11.62
12.75
13.88
15.00
16.12
17.25
18.88
19.50
20.62
22.12
DISTANCE (FT.)
ROW NUMBER
-4
-3
-2
-1
B-5
B-4
B-1
B-3
B-2
B-19
B 6D
B-6,7,8,9
B-20
B-14,15
B-16,17
B-22D
B-21,22,23,24
B-10,11,
12,13
LEGEND
+ PLANNED COLUMN CENTERS
• FIELD MEASURED COLUMN CENTERS WITH CIRCUMSCRIBED 3-FOOT DIAMETER COLUMN AREA BY LE.
× 2 7/8" CORES
⊙ 2 1/8" CORES

Figure 12. Location of soil columns in Sector B.

bring the slurry density to the targeted value. The slurry tank was sufficiently large to prepare enough slurry to treat three or four soil columns with each batch.

The operator then pumped the slurry to the mixing auger at a preset and controlled ratio to the soil penetration rate. Water also was fed to the auger on a ratio controlled by the slurry rate. Two water ratios were used, depending upon whether auger penetration was above or below the water table. Slurry was added on the downstroke, and additional mixing with the soil occurred on auger withdrawal. Typically, each column of treated soil -- with locating of the crane and aligning the auger -- took thirty minutes.

In Sector B all primary strokes were performed before any secondary strokes. Thus, Geo-Con was able to auger the secondary columns 24-48 hours after the primary columns started to set. In Sector C, primary and secondary columns were performed alternately due to logistical difficulties in moving the crane.

The soil was treated to a depth of 18 ft in Sector B and 14 ft in Sector C. For the bottom 3 ft, sodium silicate was added to provide a quick setting, more impervious treated-soil-mass.

The sampling contractor returned to the site on May 16, 1988 -- approximately thirty days after the remediation. Three days were required for site preparation, similar to that performed for the pretreatment sampling. Sampling started on May 19 and was completed on June 3. Samples were collected from nineteen locations in Sector B and eighteen locations in Sector C. This is three more locations than originally intended, and these samples were added because they are close to high PCB concentration samples previously collected. All SITE project work at the electric service shop was completed by June 6, 1988.

For the 6-day demonstration plus mobilization/demobilization, Geo-Con utilized eleven people, as follows:

1	overall coordinator
1	construction manager
1	control-panel and operations-control supervisor
1	outside operation supervisor
2	crane operator and helper
1	operator at auger
1	operator at slurry feed system
1	hydraulic power-pack mechanic
1	electrician
1	health and safety officer

A detailed log of the six days of operation is described in Volume II, Appendices A and B. The log provides operating data collected from the control panel by EPA, and GE and records many additional observations. The summary report prepared by Geo-Con for GE is provided in Volume II, Appendix C.

7.2 UNIT PROBLEMS AND DEVIATIONS FROM DEMONSTRATION PLAN

7.2.1 Operations

Equipment operations during the demonstration were quite satisfactory. However, some minor problems were encountered, along with deviations from the plan. These operational deviations are as follows:

- Sector B was to contain 20 primary columns and 16 secondary columns, with the end columns of each of 4 rows of 9 being primary (see Fig. 10). The deviation was that 2 rows started with secondary columns (Rows 1 and 3 from the north end), and thus there were 18 columns of each type. This deviation should not have a significant impact on the results.

- The preferred procedure described by Geo-Con for treating soil columns was to drill all the primary columns (strokes) in each sector first before augering the secondary columns. In Sector C this did not occur, as most secondary columns were done after their corresponding primary column. Practical difficulties of moving the crane and aligning the auger necessitated a reduction in the number of times the crane would be moved. A primary and a secondary column could be mixed without relocating the crane. The impact of this deviation was not detected and was not expected to be of significance. The added curing time of the primary columns in Sector B (compared to those in Sector C) did not impact Geo-Con's ability to auger the secondary columns.

- Automatic control of the slurry and supplemental water feed rates could not be maintained, and some of these operations had to be performed manually. Manual operation was used for most of Sector C (the second one done), which resulted in an overall reduction in the ability to control flow and in uneven feed additions per foot of depth. This problem resulted in part from the oversized design of the feed system, which was sized for the larger, 4-auger commercial unit. In some instances, slurry and water were not added for a depth of 6 to 9 in., then would be compensated for in the next 6 to 12 in. Lesser variations were not uncommon. This would leave significant variations in quantity of additive per foot of penetration. However, the total slurry added was close to the targeted value. Although auger mixing was good and tended to blend the soil along the vertical column, this deviation may have an impact on the solidified mass and samples collected. This impact may be greater than the small deviations in slurry density (solids concentration in additive slurry). A detrimental impact, due to the uneven HWT-20 feed rate, was not noted in the analytical results.

- The sodium silicate was not added uniformly over the final 3 feet of depth. To compensate for this and for the incomplete mixing in the bottom region, the auger was cycled one additional time over a 3 1/2- to 4-ft range before withdrawal. This mixing penetrated the soil an additional 6 in., thereby spreading the two additives through more soil. The average sodium silicate feed to the bottom 3 1/2 ft was about 4.2% of dry HWT-20 additive. This addition is low compared to the target value of 5% for the bottom 3 ft.

- Some difficulties were encountered in starting the auger penetration in Sector C, particularly with the secondary columns. This was due to large stones in the backfill comprising the top 5 ft of this sector. This added 5-10 min to many of the columns' augering times, with Column 66 taking about 40 min to start. Some very minor difficulties in auger penetration, due to the harder limestone layer, were encountered in Sector B.

- A major water leak developed at the auger head where water enters. Therefore, except when sodium silicate was added, the supplemental water was turned off for the last 21 soil columns, on the instructions of GE, to minimize time loss. However, based on laboratory results, the moisture content for these solidified soil columns appears to be approximately equal to that of the earlier columns in this sector when additional water was added.

- Location of the auger head deviated from the target point by many inches in many cases. The exact locations of the auger or column centers in Sector B were measured, and a number of untreated soil areas are apparent. Geo-Con's drilling plan precluded untreated areas due to the overlapping of properly situated columns. Geo-Con claims the actual mixing zone is slightly larger than the 36-in.-diameter columns shown in Fig. 12, and thus the size of the poor overlap areas would be reduced. This difficulty should be overcome with the use of Geo-Con's multi-augered machine, which should provide improved penetration control. Samples at locations B-10, 11, 12, and 13 bordered an untreated area (unsatisfactory overlap of soil columns); as the soil was loose or weakly bonded, treated soil cores could not be collected. Therefore, additional samples at locations B-21, 22, 23, and 24 were collected at a soil column center about 1.5 ft to the northwest. The auger head also deviated from the target locations in Sector C, but no measurements of the column locations were made, and void areas were not noted during the core sampling.

- The nature of the auger operation, injecting additive on the downstroke with additional mixing on the upstroke, causes vertical soil blending. In addition, grout from one column overflowed into others. Therefore, both vertical and horizontal soil blending occurred, making it impossible (as predicted) to maintain the integrity of local contaminant hot spots for physical and chemical analyses.

- The summary sheets prepared by Geo-Con used slurry densities about 5% higher than actually measured by GE. Thus, using the Geo-Con numbers, the HWT-20 usage would be even greater than calculated in Section 7.4. The correct numbers, based upon GE provided density values, were used for the material balance in Table 14.

- A few other minor operating difficulties were encountered, but these caused only momentary delays. Many of these upsets are recorded in Appendix A.

7.2.2 Sampling and Analysis

Some deviations also occurred during the sampling and analysis work. They are as follows:

- Based upon preliminary untreated soil analyses and the operations log, some additional posttreatment samples were collected, two in Sector B and one in Sector C. The two additional samples in Sector B were taken in areas of high PCB concentration near poor column overlap areas to obtain additional data based upon both characteristics. The additional sample in Sector C was taken to obtain an additional soil-column-interface sample.

- In the lower unconsolidated soil layer, Shelby tube samples of untreated soils (for bulk density and permeability tests) could not be collected, due to the fluidity of the soil. Split spoon samples were collected, and a modified bulk density test, as described in Section 5.7, was performed.

- After approximately 40% of the posttreatment samples were collected, coring operations were changed from air cooling to water cooling. Air cooling had been attempted instead of water cooling (the more commonly used method), to avoid possible leaching of some contaminants by the cooling water. However, after switching to cooling water, analysis of the water, which is recycled, indicated only very minor losses in PCBs, based on the core mass and PCB concentration in the water. The losses would provide a small error, well below the limits of accuracy of Method 8080 for soil analysis. This change eliminated PCB contamination of the immediate area by the cooling air and increased the coring rate, which had been extremely slow (1/4 to 1/2 in./min). The change did not appear to impact the analytical results. However, the benefit was that the integrity of the sample cores improved, with less apparent loss in core sample material.

- For the Falling Head Permeability test, the test samples were presoaked outside the apparatus to start the saturation process. Then pressure higher than specified in the test procedures was used in the triaxial-cell test unit. Both presoaking and high pressures were used to reduce the time required for saturation, which had been taking many weeks. The impact on the results should be negligible.

- The diameter of the cores for the variously treated soil samples deviated from those defined in the analytical procedures. The sizes selected, 2.875 instead of 3.0 in., and 2.125 instead of 1.77 in., were used because they were the closest sizes available to the driller. The use of 2.875-in. cores for the UCS tests did not cause any errors since the length-to-diameter ratio of 2.0 was maintained. The 2.125-in. cores for the weathering tests may have had a more significant impact, although the general trend of the results would not change.

- For the wet/dry weathering tests, a convective drying oven was used instead of a vacuum oven. This increased the drying temperature (60°C) by about 2°C, which should not affect the results obtained.

SECTION 8

PERFORMANCE DATA AND EVALUATION

8.1 PHYSICAL TESTS

The results of the physical tests, the details of which are in Appendices E and F, are summarized in Tables 5 through 8 (at the end of this section). The highlights of the results, with discussion, are as follows:

8.1.1 Moisture

The moisture content of the untreated soil varied with depth, depending on whether the sample was taken above or below the water table. At a 1-2-ft depth, the moisture content averaged about 5.5 wt%. Below the water table, it averaged about 18 wt%. There was no definitive trend between moisture content and depth below the water table, or between moisture content in the two sectors (moisture content does affect the strength of cement). The average free-moisture content of the treated soil was 18.1 wt% and was the same in both sectors at all depths. The range of individual values was 12 wt% to 26 wt%. There was also no apparent relationship between the soil moisture (treated and untreated) and any of the other physical properties, such as unconfined compressive strength (UCS) or bulk density.

8.1.2 pH

The pH in water of the soil was measured for each untreated soil sample. The values were quite consistent, with the average value in Sector B being 8.0, and in Sector C, 8.5. No variations with depth were seen.

8.1.3 Particle Size Distribution

The particle size distribution for the untreated soil samples showed for Sector B that 30 wt%-40 wt% of the soil is less than 60 mesh (250 µm). About 1 wt%-3 wt% of the soil in the sand layers is less than 200 mesh (74 µm), as is about 5 wt%-10 wt% in the limestone layer. Data on the soil below the limestone layer (depth greater than 10 ft) is very limited, but appears to have a substantial fraction less than 60 mesh. This data indicates that the soil is in a proper size range for the preparation of concrete and should not have any impact on the results.

8.1.4 Total Organic Carbon (TOC) and Oil and Grease (O&G)

The TOC and O&G concentrations in the soil samples were very low. Most of the O&G values were below the detection limit of

0.1 wt%, particularly in Sector C, and the TOC values were primarily in the range of 1,000-3,000 mg/kg. At sample locations B-6 and B-7 near the oily drainage drum in Sector B, values of TOC and O&G were greater, up to 16,000 mg/kg for TOC and 1.6 wt% for O&G, respectively. In addition, it appears that at the higher TOC concentration locations, higher PCB concentrations were measured. These were also the locations where samples high in volatile organic compounds (VOCs) were detected. For nearly all the samples, TOC values were larger than O&G values, as would be expected, since O&G is the solvent extractable portion of TOC. It is usually expected that organic contents above 10% by wt. may interfere with the hydration reactions of cement and other pozzolans. Therefore, at the demonstration site, organics would not have interfered with the cement hydration reactions.

8.1.5 Bulk Density

Average bulk density of the untreated soil in Sector B increased with depth from 1.42 g/mL in the top sand layer to 1.67 g/mL in the lower sand layer. In Sector C, the top layer -- a clean backfill used to replace contaminated soil taken to a secure landfill -- had the largest average bulk density of 1.65 g/mL. The other two layers were 1.53 g/mL for the limestone and 1.57 g/mL for the lower sand, which is a little less than the Sector B value. The average overall bulk density of all the samples was 1.55 g/mL, with a range of individual values from 1.21 to 1.85 g/mL.

The treated-soil bulk density became greater with increased depth. In Sector B, the top layer averaged 1.76 g/mL, and the lower sand layer was 1.97 g/mL. In Sector C, the values ranged from 1.80 g/mL in the top layer to 2.00 g/mL in the lower layer, which is approximately the same as solidified Portland cement. The addition of sodium silicate to the additive mix in the bottom zone sampled did not appear to have an impact on the bulk density. The variability of the results for the treated soil was less than for the untreated soil. On average, the overall bulk density of the soil increased by 21% with treatment. The bulk densities obtained during the screening tests, described in Section 6.4, were about the same as for the field samples.

A review of the overall material balance in Section 8.4 showed that the total weight increase of the soil after the addition of the IWT additive, water, and sodium silicate averaged 31.7%. Therefore, the volume increase was about 8.5%, which for Sector B was equivalent to 18 in. and for Sector C, 14 in. of ground rise. This seems reasonable because the field observations showed the level of Sector B rose 1 1/2 to 2 ft, and Sector C rose about 1 to 1 1/2 ft.

8.1.6 Permeability

The average permeability of the untreated soil in both sectors, at all depths, was approximately 1.8 x 10^{-2} cm/s. The values for the limestone layer (5-10 ft depth) appeared slightly greater than for the two adjacent sandy layers. The permeability values were quite scattered, covering a range 0.1 x 10^{-2} to 12 x 10^{-2} cm/s. For most of the samples in the lower sandy soil layer, a modified bulk density (see Section 6.5 for procedure) was obtained. Samples from the lower layer showed the lowest permeabilities, but this may have been due to the procedural change.

The treated soil permeabilities ranged from 10^{-6} to 10^{-7} cm/s. No discernible differences were noted between samples above and below the water table. A guideline for satisfactory permeability used by EPA is 10^{-7} cm/sec. This is the maximum allowable value for hazardous-waste landfill liners, as suggested by EPA. However, the achieved four-orders-of-magnitude decrease in permeability by the treatment will cause the groundwater to flow around, not through, the treated soil.

The permeabilities performed on samples in the sodium silicate layer, at sample locations B-24, C-8, and C-14, were similar to values obtained without the sodium silicate. Permeabilities for the weathering tests are discussed in Section 8.1.8.

8.1.7 Unconfined Compressive Strength (UCS)

The unconfined compressive strength (UCS) of all the samples was satisfactory, easily meeting the EPA's minimum guideline of 50 psi, which provides for a high load-bearing strength. Those collected in Sector B averaged 290 psi, ranging from 75 psi at B-19 to 579 psi at sample location B-23. The average of the unconfined compressive strengths in Sector C was 536 psi, with the individual values ranging from 247 psi at sample location C-15 to 866 psi at sample location C-1. The average HWT-20 additive dosage rate in Sector B was 0.171 lb HWT-20/lb dry soil, and for Sector C, 0.193 lb HWT-20/lb dry soil.

For both sectors, the UCS appeared to increase with depth. For Sector B, it ranged at increasing depth from 249 to 410 psi, and for Sector C, from 420 to 688 psi. The highest averaged value in both sectors was in the region where sodium silicate was added.

In Sector B, it appeared that the samples taken from the center of the primary columns produced the highest average UCS -- 420 psi. For the center of the secondary columns, where the slurry flow was reduced by almost 30%, the average value was about 185 psi. The average UCS of the interface samples, where the degree of column overlap varied, was 210 psi.

In Sector C, where the HWT-20 addition for the primary and secondary columns was equal (at approximately 0.193 lb HWT-20/lb dry soil), the UCS values in the primary column centers and at the interfaces were about equal. This was not unexpected, since the actual dosage level in the soil may have been highest at the interface points where treated material overlapped. However, the UCS for the secondary column centers appeared to be higher than for the primary ones -- 620 psi versus 450 psi (for the average of the samples collected). Since a detailed logging of actual column locations was not performed, this analysis was based only on the planned column locations. More data is required to confirm these trends.

The greater strength in Sector C may have been due in part to the higher additive rate. There did not appear to be any relationship of UCS with bulk density or moisture content. The magnitude of the UCS results was consistent with the values obtained for the screening samples.

8.1.8 Weathering

The results of the wet/dry weathering tests, which showed very small sample-weight losses (0.25% to 0.50% for both the test specimens and the controls), were quite good. The weight losses of the test specimens were only slightly greater than for their respective controls, usually by less than 0.1%.

The results of the freeze/thaw tests showed very dramatic weight losses for the test specimens, while the weight loss of the controls remained small -- 0.25% to 0.70%. The weight losses ranged from 0.65% at sample location B-1 to 30.75% at sample location C-3, with the overall average value being about 7.0% in Sector B and 5.8% in Sector C. Nevertheless, this degradation may not affect PCB mobility if chemical bonding of HWT-20 to the contaminant exists, as claimed by IWT. In addition, IWT has indicated that they can adjust the additive mix formulation to be more resistant to freeze/thaw conditions. This would be done for all locations where the climate is more severe than in Florida.

On about half of the specimens that passed through the 12-cycle weathering tests, either UCS or permeability tests were performed. The UCS results showed no strength loss for the wet/dry samples. However, it appeared that a major strength loss occurred for freeze/thaw test specimens where weight losses above 3.0% occurred. For example, for sample location B-24 where there was a 10.7% weight loss, the UCS was 6 psi; and for locations B-8 and B-9, where the weight losses were 27.9% and 29.5%, respectively, the samples crumbled when the strength test started.

Eight permeability tests were performed on samples from Sector B and Sector C after the 12-cycle tests. Two were performed on wet/dry test specimens where the weight loss was very low, and six were performed on freeze/thaw test specimens where the weight loss was modest -- up to 6.0%. The results were approximately the same as for unweathered samples, ranging from 10^{-6} to 10^{-7} cm/s.

8.1.9 Laboratory Formulations

Soil samples from Sector B, Sector C, and an uncontaminated area, were solidified, using Type 1 Portland cement at 15 wt% and 20 wt% addition rates to provide a comparison to treatment with HWT-20. The results, shown in Table 9 (at the end of this section), are as follows:

- For Sector B, untreated soils from locations 4, 5, 14, 16, and 17 were blended and, based on calculations, had a PCB content of 177 ppm by wt. For Sector C, untreated soils from locations 1, 2, 5, 7, 9, and 15 were blended and had a calculated PCB content of 62 ppm by wt.
- The bulk densities were approximately the same as the field samples.
- The moisture content ranged from 3.6 wt% to 8.9 wt%, which was less than the treated soil samples.
- The UCS for the samples containing 15 wt% cement was less than for the 20 wt% samples by approximately a factor of two. The values using Sector B soil were the lowest, and were approximately equal to the field core samples. The values for Sector C and the uncontaminated soil (both with a lower moisture content than Sector B) were higher than the field samples at Sector C. The low moisture content for the uncontaminated soil and Sector C soil formulations may account for the higher UCS values observed. The quantity of water added was based upon obtaining 100% for the ASTM slump test, which was less than the amount of water used in the field operation.
- The TCLP leachates for all samples were below the detection limit of 1.0 μg/L, which was equivalent to the field sample results.

8.2 CHEMICAL TESTS

Tables 9 to 11 at the end of this section summarize the results of the chemical tests, the details of which are in Appendices E and F. The highlights of the results, with discussion, are as follows:

8.2.1 Soils

The untreated soil samples contained PCBs (Aroclor 1260), up to a maximum concentration of 950 mg/kg at location B-11. This is on the eastern end of the sector, at a depth of 7-8 ft, away from the anticipated hot spot represented by sample locations B-1, 2, 3, 4, and 5. Samples from locations B-6 and B-7, approximately 7 ft west of B-2, contained PCB concentrations of 650 and 460 mg/kg, respectively. Other relatively high concentrations of PCBs occurred at sample locations B-13, 16, and 17, all higher than any value from samples taken in Sector C. The largest PCB concentration measured in Sector C was 150 mg/kg at location C-7, which is near the southeast corner at a nominal depth of 7-8 ft.

Aroclor 1260 was the only PCB Aroclor detected in any sample taken from either sector.

The treated soil in Sector B contained PCBs up to a concentration of 170 mg/kg at location B-11, the same location where the maximum concentration was measured for untreated soil. The maximum concentration of PCBs in Sector C was 110 mg/kg at location C-3 (7-8 ft depth), which is in the central portion of the sector, and not close to location C-7 (where the highest untreated concentration was found). A comparison of treated soil versus untreated soil concentrations showed no consistent relationship, only an approximate general trend. High PCB concentrations in untreated soil locations produced relatively high PCB concentrations in the treated soil at these same locations.

A comparison of treated soil to untreated soil PCB concentrations by sector and by depth was performed. In Sector C, the quantity of PCBs was approximately equivalent before and after soil treatment. However, in Sector B, the quantity of PCBs measured in the treated soil appeared to be only about one-third of that measured prior to treatment, with slightly better accountability obtained from the near-surface samples. The most likely explanation for the PCB reductions was the vertical and horizontal dispersion of the PCBs due to the mixing involved in the remediation operation, along with a 30% dilution due to the addition of HWT-20 and water. This explanation is supported by the large change observed after treatment in VOC and heavy metals concentrations at sample locations B-6, B-7, and B-8. Another possibility that might explain this is a chemical interaction, as claimed by IWT, between the PCB molecules and the additive HWT-20. However, the PCB concentrations observed during the screening tests performed in July 1987 on samples provided by GE showed that the intended concentration level of PCBs -- about 5,000 mg/kg -- was measured during the laboratory analyses, which if chemical bonding occurred would have been much lower. Therefore, the most likely explanation is blending with surrounding soils of lower concentration.

Eight untreated samples were analyzed for volatile organic compounds (VOCs), four samples from each sector. VOCs were detected only at sample locations B-6, B-7, and B-8, with the maximum concentration of 1,485 mg/kg measured at B-6. The VOCs detected were total xylenes, ethylbenzene, and chlorobenzene, with xylenes existing in the greatest concentrations (see Table 12 at the end of this section) for individual component concentrations). Therefore, the leaching tests on these samples included measurements of VOCs.

For the treated soil samples, analyses for VOCs were made at sample locations B-6, B-6 duplicate, B-7, and B-8. The maximum VOC concentrations -- primarily xylenes -- were observed at location B-6, with a concentration of 41 mg/kg. This compares to the untreated soil, where the concentration of total VOCs at location B-6 was 1,485 mg/kg. The dilution effect of the additions would reduce the concentration of VOCs by 30%, which does not come close to accounting for the concentration changes seen. The large observed change was likely due to a combination of factors. The largest one was probably the vertical and horizontal mixing, which would blend high and low concentration soils. Other factors contributing to the VOC reduction may include volatilization in the field due to soil disturbance, laboratory preparation procedures before analysis (e.g., sample crushing), and the extended hold time before analysis. Although the samples were kept refrigerated, the maximum allowable hold time of 10 days was exceeded by 3-4 weeks. However, any analyses for VOC immobilization compares the ratios of a contaminant in the soil to its leachate for the treated and untreated soils, thus, the absolute values are of less importance. Another possibility is that the loss was due to chemical interaction with HWT-20, although no direct evidence from the Demonstration Test supports this.

Analyses for the thirteen priority pollutant metals in untreated soil were performed on six samples from each sector. The only significant concentrations were found at sample locations B-6, B-7, and B-8, and are summarized in Table 13 (at the end of this section). The primary metals detected were chromium, copper, lead, and zinc, with some samples containing small amounts of nickel, cadmium, antimony, and arsenic. No analyses were made for these latter metals in the treated soil or leachates. The maximum untreated concentration of metals was at location B-6, where the total quantity was about 5,000 mg/kg. The metals concentration in the treated soil ranged from 80 to 279 mg/kg. This is a major change from the untreated soil, a reduction of about 90%, which is probably due to the soil- mixing/treatment operations. This metal data provides corroboration for the above explanation on the reduction of VOC and PCB concentrations in the treated soil.

8.2.2 Leachates

For each of the untreated soil samples, PCBs were analyzed for in the TCLP leachates. In Sector C, where the maximum PCB concentration in the untreated soil was 150 mg/kg, all leachates (except in sample C-11) contained PCBs below the normal detection limit of 1.0 μg/L of Aroclor 1260. In Sector B, PCBs were detected in more than half of the untreated soil leachates. Except for sample B-7, (a wild point) where the concentration was 400 μg/L , the values ranged from 1 to 13 μg/L .

Of the eleven Sector B untreated samples with detectable PCBs in the leachates, five samples had soil concentrations of 63 to 140 mg/kg. Except for B-15 (63 mg/kg), the concentrations in the leachate were 1.1 to 1.6 μg/L. The other six samples, with soil concentrations of 300 mg/kg and above, had leachate concentrations ranging from 1.8 to 12 μg/L , except for B-7 (400 μg/L). Two soil samples, B-8 and B-13, with PCB concentrations of 200 and 250 mg/kg, respectively, had leachate concentrations below detection limits. Therefore, with PCB concentrations below 300 mg/kg in the soil, PCBs cannot always be detected in the leachates.

For the treated soils in both sectors, Aroclor 1260 was not detected in any leachate based on the original analyses with a detection limit of 1.0 µg/L. Only four treated-soil samples reported PCB concentrations of 100 mg/kg or more, with a maximum of 170 mg/kg. Based on expressed concerns of both IWT and GE that the PCB detection limit of 1.0 µg/L was too high, additional analyses of some of the TCLP leachates, which had been stored at 4°C, were performed. A modification in Method 8080 was used to obtain a detection limit of 0.1 µg/L. Four of the seven treated soil leachates were below the new detection limit. Of the six untreated soil leachates, five were less than previously measured and in general were in only fair agreement with the earlier results; see Tables 10 and 11 at the end of this section.

Based primarily upon these additional leachate analyses, it appears that the process immobilized PCBs. However, since almost all of the PCB concentrations in the TCLP leachates were very close to the detection limits, some uncertainty remains whether the PCB immobilization took place or not. The screening sample results performed under the direction of EPA, using laboratory-prepared samples supplied by GE, reported TCLP leachate analyses for three samples of less than 1.0 µg/L. The solidified soil samples contained 4,100 to 5,700 ppm PCBs, significantly higher than the demonstration samples (170 ppm maximum). The formulation tests, using cement as a substitute for HWT-20, also showed that the PCBs in the leachates were below the detection limit of 1.0 µg/L.

TCLP leachate results for VOCs were obtained on both the untreated and treated soils for samples from locations B-6, B-7, and B-8. The results showed leachate concentration of VOCs from the untreated soils of 2,490 to 7,890 µg/L. For the treated soil, the leachate concentrations ranged from 320 to 605 µg/L. For each of the three VOCs -- total xylenes, chlorobenzene, and ethylbenzene -- concentrations were reduced by an equal factor from the untreated soil leachate to the treated soil leachate; leachate reductions were less than the corresponding soil concentration changes. However, the treated-soil leachate concentrations were quite low and may not decrease very readily below the levels measured. IWT claims the composition of their additive was tailored only to PCB immobilization, and could be changed should the immobilization of VOCs be required.

TCLP leachate results for the four heavy metals detected in the soil were obtained on both the untreated and treated soils for sample locations B-6, B-7, and B-8. The results showed untreated soil leachate concentrations ranging from 320 µg/L for sample location B-7 to 2650 µg/L for sample location B-6. For the treated soil, the leachate concentrations ranged from 120 µg/L for sample location B-7 to 210 µg/L for sample location B-6. The results showed lower treated-soil TCLP leachate concentrations compared to untreated-soil leachates for lead and zinc; values for chromium and copper increased. However, the leachate values for the soil samples after treatment were very low, and were obtained only for three samples, so immobilization of heavy metals could not be determined in this project.

Soil samples from sample locations B-6 and B-7 were leached using the ANS 16.1 and MCC-1P procedures both with site water (PCBs were not detected in the site water) and deionized water. In addition, the ANS 16.1 leach test was used for sample locations C-2 and C-4 and leach test MCC-1P was used for sample locations C-1 and C-3; all with deionized water. For MCC-1P, samples of leachate were collected after 3, 7, 14, and 28 days. For ANS 16.1, samples of leachates were collected after 1, 3, 7, 14, and 28 days. The latter test uses fresh leach water at each time interval for the same solid sample, while MCC-1P involves four parallel leach tank operating at $40^{o}C$, each running for a different time period. VOCs and PCBs were not detected in any of the leachates, for all six sets of samples, for both leaching tests. This differs from the TCLP results, where VOCs were measured in some of the leachates. Thus, as expected, leaching from a solid sample is less than from a crushed sample, which contains more surface area.

8.3 MICROSTRUCTURAL STUDIES

Microstructural studies were performed on untreated and treated soil samples. All analyses were performed three to four months after soil processing. All samples were studied by scanning electron microscopy (SEM), optical microscopy, and X-ray diffraction (XRD). Energy dispersive X-ray spectrometry was also performed on some samples. The type of information to be obtained from each test is:

- X-ray diffractometry: Crystalline structure of the soil and hydration products.
- Microscopy: Characterizes crystal appearance, porosity, fractures, and the presence of unaltered soil waste-material.
- Energy dispersive x-ray spectrometry: Elemental analysis, e.g., calcium, aluminum.

Microstructural and microchemical analyses are proven methods for understanding the mechanism of structural degradation in materials similar to those in this demonstration. The literature is replete with examples of SEM and XRD analyses of soils, cement, soil-cement mixtures, and each of those mixed with various inorganic and organic compounds. However, there have been relatively few studies of the microstructure of complex waste/soil mixtures like those resulting from stabilization/solidification procedures. Consequently, in some cases interpretation of microstructural observations may be difficult. The microstructural report is intended to be complete in its reporting, yet conservative in its conclusions.

The detailed report with photographs and X-ray diffraction patterns is included in Appendix D.

The results can be summarized as follows:

- The two most important mineral phases in the samples studied were quartz and calcite. This would be expected, based on the geological structure of the Hialeah area.

- The morphology of the samples showed subangular clastic grains of quartz or calcite, cemented by much finer-grained binder material. The bulk of the binder has a crude layered appearance, usually at most a few micrometers thick. Needles of ettringite are extremely common, much more common than is observed in a Portland cement sample of a typical water/cement ratio of 0.4. The presence of large amounts of ettringite in a Portland cement sample is a symptom of sulfate attack, which can in some cases lead to structural failure due to expansion. The extra sulfate required for extensive ettringite formation could come from the gypsum that was found in the untreated soil. However, IWT indicated that the HWT-20 formulation contains a higher content of gypsum than a normal cement mix. It is not known whether ettringite observed in the treated soils will necessarily lead to expansive failures, as it is claimed to be a part of the IWT chemical fixation technology. The presence of the ettringite, according to Professor Perry in London (see Appendix D), may aid the immobilization of metals.

- Treatment of the contaminated soil by the IWT process produced a dense, homogeneous mass with low porosity. Low porosity reduces the susceptibility of damage from wet/dry, and particularly freeze/thaw weathering cycles, by reducing the quantity of water in the pores of the solid that could freeze and fracture the solid.

- All the ettringite analyses showed the presence of high amounts of silicon, which is not expected in the normal formula. This is also claimed to be a part of the IWT technology.

- The quantity of portlandite, a common crystalline phase in cement, was less than usual. This is probably not a significant factor.

- Variation of properties in the vertical and horizontal directions appeared to be absent. No significant difference in hydration products between quartz-rich and calcite-rich samples was observed. The mixing operation probably led to thorough vertical and some horizontal mixing, thus explaining apparent consistency.

8.4 MATERIAL BALANCE

A material balance, summarizing daily operations, is provided in Table 14 (at the end of this section). It shows the actual additive usage (not including spills and line flushing) was approximately 61.2 tons; sodium silicate usage (41^{0} Baume) was 2,440 lbs.; and overall dosage rate of the HWT-20 additive was 0.171 lb dry additive/lb dry soil for Sector B, and 0.193 lb/lb dry soil for Sector C. Part of the reason the additive rates of HWT-20 were higher than the targeted value of 0.15 lb/lb dry soil was that the average bulk density of the untreated soil was 1.55 g/mL (96 lb/ft^{3}) compared to the previously measured (by GE) value of 1.68 g/mL (105 lb/ft^{3}).

8.5 DATA QUALITY ASSURANCE

8.5.1 Sampling and Analysis

In Section 7 of the approved Quality Assurance Project Plan (QAPP - Level II), it was indicated that various Quality Control (QC) samples would be taken to control and/or assess data quality. These are:

- Laboratory blanks - deionized water taken through sample preparation steps.
- Field blanks - clean water samples brought from the field and then analyzed in the laboratory to check for field contaminations.
- Surrogate standards - deuterated or halogenated compounds that respond similarly to the compounds of interest were added to all samples and blanks for PCB and VOC analyses during sample preparation. The recoveries of the surrogate compounds are used to isolate problems that will occur throughout the entire analytical procedure.
- Spiked samples - samples were spiked with known contaminants to confirm analytical recoveries and thus accuracy of the analyses. Duplicates on the spiked samples were also performed.
- Duplicate samples - duplicate samples from the field were collected and analyzed to confirm soil sample data.

To verify that correct sampling procedures were used, EPA sent a Quality Assurance (QA) person to the field to observe sampling procedures. In addition, QA personnel went to the analytical laboratory to observe and correct, if necessary, procedures being used.

The purpose of the QA/QC program was to fulfill two related purposes:

- To provide an organized frame work for sampling and analytical efforts.
- To control data quality within preestablished limits to ensure that it was adequate to achieve the objectives of the program.

The laboratory provided the following information on the quality control data:

8.5.1.1 Calibration Data--

- PCB Analyses - All of the initial three-point calibrations and calibration verifications met acceptance criteria outlined in Section 7 of the Quality Assurance Project Plan (QAPP) during the pretreatment phase of the project. During the posttreatment phase, calibration verifications at the end of runs on 7/11/88 and 7/12/88 did not recover within the required ± 15 wt%. New initial three-point calibrations were generated the following day as required. Samples analyzed prior to the out-of-control calibration verifications were quantitated using the response factors from the last in-control standard.
- Volatile Analyses - Tune initial and continuing calibration acceptance criteria outlined in Section 7 of the QAPP were met for each twelve-hour analysis period during the pretreatment and posttreatment phases of the project.
- Metals Analyses - Instrument calibration and calibration verification acceptance criteria outlined in the QAPP were met for all metals analyses during both the pretreatment and posttreatment phases of the project.

8.5.1.2 Method Blank Analyses--

- PCB Analyses - For the pretreatment phase, four method blanks were extracted with soil samples to be analyzed for PCBs. Seven water method blanks were extracted with leachate samples to be analyzed for PCBs. During the posttreatment phase, three soil and twelve water blanks were extracted, along with soil and leachate samples for PCB analysis. Acceptance criteria were met for all blanks.
- Volatile Analyses - Three low-level blanks and one medium-level blank were analyzed, with soil samples analyzed for volatiles during the pretreatment phase. Six low-level and three medium-level soil and eighteen low-level water blanks were analyzed with soil and leachate samples during the posttreatment phase. Three pretreatment and seventeen posttreatment blanks contained detectable concentrations of

laboratory solvents and/or target compounds at less than the maximum concentration allowed in the QAPP.

When samples associated with these blanks were found to contain compounds also present in the blank, the reported result was flagged with a "B" qualifier to indicate possible blank contamination. These results should be considered accordingly. The laboratory contaminants were usually acetone and methylene chloride, which are not the VOCs found at the site.

- Surrogate and MS/MSD Analyses - The mean and standard deviation of percent recoveries of surrogate and matrix spike standards added to samples and blanks is listed below for PCB analyses. The number of values used to calculate the ranges is given in parentheses ().

8.5.1.3 PCB Analyses--

	Nonochlorobiphenyl (Cl-9)	MS/MSD
o Pretreatment Phase		
PCB/Soil	96±13 (38)	111±16 (10)
PCB/Leachate	92±20 (59)	96±20 (10)
o Posttreatment Phase		
PCB/Soil	106±17 (29)	100±13 (12)
PCB/Leachate	99±11 (63)	86±12 (12)

The surrogate standard nonochlorobiphenyl (Cl-9) was added to each solid sample, leachate, and blank prior to extraction for PCBs. The recovery of the surrogate was calculated as the percent ratio of the concentration found divided by the concentration added.

The matrix spike/matrix duplicate (MS/MSD) analyses for PCBs were one in ten samples by the addition of a known amount of an Aroclor to the sample selected prior to extraction. Aroclors 1016, 1232, 1242, 1248, 1254, and 1260 were alternately added. The recoveries were outside acceptance limits for three samples.

A method blank for PCBs was prepared for each day's samples were extracted. There were a few days (see Appendix F) where the surrogate recoveries were high.

Surrogate recoveries were above acceptance limits for the ten leachates analyzed during the pretreatment phase for PCBs. Corrective action was not taken because of the limited amount of sample. Results reported for these samples may be ten to thirty percent higher than what is actually present. The samples involved are defined in Appendix F.

The relative percent difference (RPD) was within acceptance limits.

8.5.1.4 Volatile Analyses--

The mean and standard deviations of percent recoveries of matrix spikes were as follows:

- o Pretreatment Phase

	Tol-d8	BFB	DCE-d4 .	MS/MSD
VOC/low-level soil	107±10	101±10	92±8 (17)	102±8 (10)

- o Posttreatment Phase

VOC/low-level soil	99±6	103±7	95±9 (10)	117±23 (10)
VOC/medium-level soil	96±4	99±4	89±5 (10)	72±14 (10)
VOC/leachate	97±4	99±4	96±6 (109)	87±8 (50)

For VOCs, 1,2-dichloroethane-D4, 4-bromofluorobenzene, and D8-toluene were used as surrogate standards. All recoveries for water samples for both pretreatment and posttreatment samples were within acceptance limits, but a few of the VOC analyses for soil samples were high and outside the acceptance limits. Agreement between duplicates was good.

A matrix spike/matrix spike duplicate analysis was performed for one in ten samples on both the soil and leachates by the addition of the following: 1,1-dichloroethylene, trichloroethylene, chlorobenzene, toluene, and benzene. Three MS/MSD spikes in the pretreatment phase were performed. Two of the three were improperly performed by the laboratory technician. The other sample and the surrogate spikes met acceptance criteria. Therefore, it is expected that the accuracy of the results should be acceptable.

For the posttreatment samples, hold times to perform the volatile analyses were missed for all the samples. Additionally, some of the leaching analyses performed for the project did not use the zero headspace extractor. Thus, some volatile material in these tests were lost during the leaching tests. Values reported in Table 12 used the zero headspace apparatus. Although the samples were held beyond the 14-day hold time allowed (at 4°C), the evaluation of VOC immobilization is based on ratio of soil concentration to leachate concentration and would probably not be affected by unnecessary VOC losses.

The relative percent difference (RPD) was within acceptance limits for volatile organics MS/MSD analyses.

8.5.1.5 Metals Analyses--

For the heavy metals, soil samples for the pretreatment and the posttreatment were analyzed for method blanks, spike recoveries, and duplicates. The spike sample recoveries were all within acceptance limits of 70% to 130%. The relative percent difference between duplicates with only two exceptions was within 20%. For the four metals found at the Hialeah site, all values were within 12% except for one value of 22% for copper. All atomic absorption instruments were zeroed with a blank solution prior to analysis. Therefore, the accuracy of the results should be satisfactory.

- For the physical tests -- moisture, bulk density, unconfined compressive strength, weathering (wet/dry and freeze/thaw), and permeability -- a quality assurance program was not performed, other than some equipment calibrations. However, sufficient samples were taken in the program to provide confidence in the results obtained.

- For a few of the bulk densities of the untreated soils, the moisture content of the soil was so great, causing the sample to flow, that a Shelby tube sample could not be collected. Therefore, the sample was collected in a split spoon and a modified bulk density was performed, as described in Section 6.5.

8.5.2 Operations

An operations quality assurance plan was prepared for GE as part of the Remedial Action Work Plan for the site in December 1987. The following description is taken from the quality assurance section of this work plan.

The quality assurance officer was provided by GE. His functions for the site remediation in which the remediation of Sector B and Sector C is the first part are as follows:

- Oversee quality assurance aspects of operations.

- Review and approve project planning documents.

- Monitor remedial operations for adherence to QA procedures.

- Review data for adherence to data quality objectives.

Injection point locations were to be plotted on a site survey drawing, and these points were to be positioned so that no untreated areas were allowed between injections. In fact for the remediation of the two test sectors, the QA officer monitored the auger positioning, but did not control it to prevent untreated areas, which did occur. Only Sector B, the first sector treated, was monitored. In addition, the quality control officer monitored the depth of most of the soil columns in Sector B (see Appendix B).

The quantity of HWT-20 was also monitored and controlled by the QA officer. A curve of slurry density versus percent solids, based on actual field measurements of various HWT-20 slurry concentrations, was prepared. A one-liter graduated cylinder was filled and weighed on a triple beam balance. The measurements for specific gravity of each slurry batch, using a mud balance, were taken by Geo-Con, and the feed to the auger would only occur at the targeted density of 1.51 g/mL. A check of slurry density by the former method against the mud balance showed good agreement.

The targeted flow rate from the batch plant to the drill auger was intended to be 0.15 ± 0.005 lb of HWT-20 per pound of dry soil, based on a soil density of 105 lb/ft^3. In actuality, the soil densities were lower (96 lb/ft^3), causing the additive dosage rate to be high; this accounts for a major part of the high average dosage rates described in Section 8.4.

The batch plant flow meters, mud balances, and rotary valve on the HWT-20 silo were all calibrated by Geo-Con before coming to the field. The documentation for these calibration tests is in the Geo-Con report to GE, and is included as Appendix C.

TABLE 5. PHYSICAL PROPERTIES OF UNTREATED SOILS - SECTOR B

Sample designation(b)	Moisture content %	Bulk density g/mL	pH	Oil & grease %	TOC mg/kg	Permeability x 10^2 cm/s(c)
B-1	2.8	1.50	-	<0.1	2,100	1.6
B-2	3.0	1.56	7.7	0.1	1,300	1.0
B-3	6.4	1.21	8.4	<0.1	2,900	1.0
B-4	4.7	1.41	7.6	0.1	2,050	0.76
	4.1	1.55	7.5	<0.1	1,600	0.50
B-5	3.6	1.28	7.3	0.1	2,600	1.2
B-6	13.3	1.46	11.2	0.8	16,000	1.4
B-7	13.3	1.74	8.3	1.6	12,000	6.0
B-8	16.8	1.85	8.1	0.4	3,100	0.98
B-9	24.8	1.59(a)	7.8	<0.1	< 100	0.15
B-10	6.3	1.25	8.5	<0.1	< 100	2.6
B-11	34.9	1.58	7.8	0.2	8,100	0.05
B-12	15.6	1,52, 1.63(a)	8.1	<0.1	920	0.91
B-13	22.5	1.46, 1.73(a)	7.8	0.3	1,500	0.05
B-14	3.2	1.52	7.7	0.1	320	0.98
B-15	9.7	1.83, 1.46	8.1	0.8	960	2.1
B-16	7.5	1.30	7.9	0.1	11,000	3.7
B-17	12.4	1.85	8.2	0.8	9,650	0.13
	12.3	1.32	8.3	0.7	9,400	0.55

(a) Modified bulk density using split spoon.

(b) Sample locations
B-1, 2, 3, 4, 5, 6, 10, 14, 16 at a depth of 1-2 ft
B-7, 11, 15, 17 at a depth of 7-8 ft
B-8, 12 at a depth of 11-12 ft
B-9, 13 at a depth of 16-17 ft.

(c) All the values shown are the permeability multiplied by 10^2. For example, B-1 permeability is $1.6\text{x}10^{-2}$ cm/s and, when multiplied by 10^2, is reported as 1.6.

TABLE 6. PHYSICAL PROPERTIES OF UNTREATED SOILS - SECTOR C

Sample designation(b)	Moisture content %	Bulk density g/ml	pH	Oil & grease %	TOC mg/kg	Permeability x 10^2 cm/s
C-1	16.7	1.37	8.6	0.4	5,200	0.58
C-2	14.6	1.29	8.5	<0.1	1,800	24.0
C-3	17.1	1.67	8.2	0.4	8,200	3.6
	14.8		8.2	0.2	6,600	0.27
C-4	9.1	1.49	8.7	0.2	1,700	2.1
C-5	9.1	1.66	8.3	0.2	1,100	7.0
C-6	5.7	1.62	8.6	<0.1	2,000	1.0
C-7	20.2	1.61	8.5	<0.1	3,200	0.84
C-8	14.7	1.69	8.4	<0.1	800	0.83
		1.60(a)				
C-9	5.9	1.60, 1.74	8.6	<0.1	2,500	3.5, 1.7
C-10	8.2	1.63(a)	8.5	<0.1	1,800	1.3
C-11	19.5	1.39(a)	8.5	<0.1	1,100	1.1
C-12	5.7	1.63	8.7	<0.1	1,600	2.0
C-13	12.5	1.82	8.4	0.2	2,400	0.18
C-14	23.5	1.63	8.3	<0.1	1,500	0.35
		1.59(a)				
C-15	5.3	1.66	8.7	<0.1	2,400	0.81
C-16	15.1	1.20	8.6	<0.1	1,300	12.0
C-17	23.2	1.65, 1.60(a)	7.9	<0.1	1,300	0.27

(a) Modified bulk density using split spoon.

(b) Sample depth
C-6, 9, 12, 15 at 1-2 ft
C-1, 2, 3, 4, 5, 7, 10, 13, 16 at 7-8 ft
C-8, 11, 14, 17 at 11-12 ft.

TABLE 7. PHYSICAL PROPERTIES OF TREATED SOILS - SECTOR B

Sample designation	Moisture content %	Bulk density g/mL	Compressive strength psi	Permeability $\times 10^7$ cm/s	Weathering tests specific wt loss, %(a) W/D	F/T
B-1(i)	15.7	1.78	492	1.4	0.38	0.65
B-2(i)	9.9	1.72	330 508	---	0.32	1.48
B-3(i)	20.3	1.74	172	3.3	0.37	2.07
B-4(i)	17.6	1.81	206	0.79	0.42	3.34
B-5(i)	31.1	1.66	86	2.3	0.37	
B-6	23.1	1.77	114	4.2	0.43	1.84
	12.9	1.75	115		0.49	
B-7	24.7	1.81	173	21.0		3.04
B-8(i)	19.0	1.88	303	5.9	0.34	27.92
B-9(i)	15.5	1.96	470		0.53	29.53
B-10(i)	--	--	--			
B-11(i)	12.9	2.24	321			
B-12(i)	--	2.15	204			
B-13	--	--	--			
B-14(i)	20.2	1.78	221		0.44	1.66(f)
B-15(h)	21.2	1.83	256		0.40	6.06(g)
B-16(i)	26.5	1.81	413			4.37
B-17(i)	13.3	1.82	507		0.26	1.10
B-18	--	--	--			
B-19(i)	19.1	1.58	75	11.0		
B-20(h)	17.6	1.79	199	2.6	0.46	0.87
B-21(j)	18.1	1.92	479	8.3	0.39(b)	1.34(d)
B-22(j)	20.9	1.99	428	4.1	0.39(c)	6.05(e)
	22.9	1.76	177			
B-23(j)	17.2	1.98	579	3.5	0.27	23.28
B-24(j)	20.1	1.90	351	3.5	0.41	10.73

(a) Reported as percent loss of starting weight on a dry basis. The weight losses of the W/D and F/T controls were 0.3-0.4%.
(b) Permeability after 12 wet/dry cycles = 2.7×10^{-7} cm/s.
(c) Permeability after 12 wet/dry cycles = 4.9×10^{-7} cm/s.
(d) Permeability after 12 freeze/thaw cycles = 8.9×10^{-8} cm/s.
(e) Permeability after 12 freeze/thaw cycles = 1.2×10^{-7} cm/s.
(f) Permeability after 12 freeze/thaw cycles = 3.9×10^{-8} cm/s.
(g) Permeability after 12 freeze/thaw cycles = 5.9×10^{-7} cm/s.
(h) Samples collected with only 2-1/8 in. corer.
(i) Samples collected with air cooling.
(j) 2-1/8 in. cores taken air cooled and 2-7/8 in. cores taken water cooled.

TABLE 8. PHYSICAL PROPERTIES OF TREATED SOILS - SECTOR C

Sample designation	Moisture content %	Bulk density g/mL	Compressive strength psi	Permeability x 10^7 cm/s	Weathering tests specific wt loss, %(a) W/D	F/T
C-1	18.8	1.97	866	0.24	0.35	2.06
C-2	14.3	1.93	528		0.41	8.11
C-3	20.9	1.95	482		0.27	3.94
	17.9	2.01	611		0.31	30.75
C-4	20.2	1.96	656		0.38	2.53
C-5	14.6	1.95	294		0.40	3.12
C-6	12.3	1.91	567	1.0	0.34	1.65
C-7	11.7	1.82	343	6.4	0.31	1.97(c)
	20.0	1.91	524		0.38	
C-8	15.9	2.00	813	4.1	0.39	0.72
C-9(d)	20.8	1.95	460		0.32	1.70
C-10(d)	18.9	1.93	466		1.68	0.88
C-11(d)	19.7	1.97	783		0.27	0.99
C-12(d)	23.8	1.84	409	1.6	0.40	4.20(b)
C-13(d)	15.5	1.99	553	1.9	0.25	8.04
C-14(d)	13.5	1.99	636	2.2	0.31	20.98
C-15(d)	18.0	1.80	247		0.33	2.14
C-16(d)	15.4	2.02	435	4.6	0.30	2.57
C-17(d)	16.7	2.02	521	2.5	0.29	2.95
C-18(d)	16.1	1.91	530		0.32	14.45

(a) Reported as percent loss of starting weight on a dry basis. The weight loss of W/D and F/T controls were 0.3-0.4%.

(b) Permeability after 12 freeze/thaw cycles = 3.0×10^{-8} cm/s.

(c) Permeability after 12 freeze/thaw cycles = 2.3×10^{-7} cm/s.

(d) Sample collected with only 2-1/8 in. corer.

(e) All samples collected used water cooling.

(f) All values shown are the permeability multiplied by 10^7. For example, C-8 permeability is 4.1×10^{-7} cm/s and, when multiplied by 10^7, is reported as 4.1.

TABLE 9. RESULTS OF FORMULATION STUDIES

Property	Clean Soil		Sector B		Sector C	
	15% cement	20% cement	15% cement	20% cement	15% cement	20% cement
Slump flow, %	139.8	102.8	58.1	79.7	129.7	116.5
Moisture content, %	3.6	4.0	5.1	5.0	8.9	8.9
Bulk density, g/mL	2.01	2.02	2.01	2.03	1.88	1.81
UCS, psi	740	1770	1332	--	170	318
TCLP Aroclor 1260, µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

TABLE 10. PCBs IN SOILS AND LEACHATES - SECTOR B

	PCB concentration			
Sample designation	Untreated soil mg/kg	Untreated soil TCLP leachate, µg/L	Treated soil mg/kg	Treated soil TCLP leachate, µg/L
B-1	52	< 1.0	40	<1.0
B-2	74	1.2	53	<1.0
B-3	55	1.0	40	<1.0
B-4	88	1.1	41	<1.0 (<0.1)
	78	1.6		
B-5	16	< 1.0	18	<1.0
B-6	650	12.0 (15)	35	<1.0
			63	<1.0 (0.15)
B-7	460	400.0 (250)	82	<1.0 (0.12)
B-8	220	< 1.0	9.6	<1.0
B-9	16	< 1.0	< 1.0	<1.0
B-10	1.1	< 1.0	--	--
B-11	950	7.2 (0.33)	170	<1.0 (<0.10)
B-12	140	1.1	16	<1.0
B-13	250	< 1.0	--	--
B-14	26	< 1.0	11	<1.0
B-15	63	13.0	7	<1.0
B-16	300	3.7 (0.50)	100	<1.0 (<0.10)
B-17	490	4.2	100	<1.0 (0.20)
	500	1.8 (1.0)		
B-18	--	--	--	--
B-19	--	--	97	<1.0
B-20	--	--	50	<1.0
B-21	--	--	60	<1.0
B-22	--	--	130	<1.0
			98	<1.0
B-23	--	--	< 1.0	<1.0
B-24	--	--	1.6	<1.0

( ) Repeat analyses of existing TCLP leachates, analyzed to a detection limit of 0.1 µg/L. Original analyses performed to a detection limit of 1.0 µg/L .

TABLE 11. PCBs IN SOILS AND LEACHATES - SECTOR C

	PCB concentration			
Sample designation	Untreated soil mg/kg	Untreated soil - TCLP leachate, μg/L	Treated soil mg/kg	Treated soil - TCLP leachate, μg/L
C-1	98	< 1.0	20	<1.0
C-2	2.5	< 1.0	19	<1.0
C-3	96	< 1.0	110	<1.0
	92	< 1.0	3.5	<1.0
C-4	9.1	< 1.0	40	<1.0
C-5	27	< 1.0	22	<1.0
C-6	16	< 1.0	26	<1.0
C-7	150	< 1.0	16	<1.0
			27	<1.0
C-8	15	< 1.0	5.9	<1.0
C-9	17	< 1.0	20	<1.0
C-10	86	< 1.0	80	<1.0 (<1.10)
C-11	16	1.3	45	<1.0
C-12	23	< 1.0	4.7	<1.0
C-13	32	< 1.0	1.2	<1.0
C-14	1.8	< 1.0	1.0	<1.0
C-15	80	< 1.0	17	<1.0
	46			
C-16	13	< 1.0	6.0	<1.0
C-17	< 1	< 1.0	< 1.0	<1.0
C-18	--	--	7.1	--

( ) Repeat analysis of existing TCLP leachate analyzed to a detection limit of 0.1 μg/L .

TABLE 12. TOTAL VOLATILE ORGANICS IN SOILS AND LEACHATES

Sample designation(b)	Untreated soil mg/kg	Untreated soil leachate µg/L	Treated soil mg/kg	Treated soil leachate µg/L
B-6				
Total xylenes	1,300	3,700	35.0	30
Chlorobenzene	65	280	1.9	<5
Ethylbenzene	120	440	4.4	<5
Total	1,485	4,420	41.3	30
B-6d(a)				
Total xylenes	--	--	32.0	<13
Chlorobenzene	--	--	2.2	<13
Ethylbenzene	--	--	4.6	<13
Total			38.8	<13
B-7				
Total xylenes	560, 1,000	6,600	34.0	430
Chlorobenzene	20, 150	290	2.5	54
Ethylbenzene	74, 28	1,000	4.5	120
Total	916 avg.	7,890	41.0	604
B-8				
Total xylenes	140, 190	2,100	1.7	270
Chlorobenzene	5, 7	100	<1.2	19
Ethylbenzene	13, 23	290	0.66	36
Total	189 avg.	2,490	2.4	325

(a) Duplicate.

(b) Depth of samples are: B-6 at 1-2 ft; B-7 at 7-8 ft; and B-8 at 11-12 ft.

TABLE 13. TOTAL OF FOUR PRIORITY POLLUTANT METALS IN SOILS AND LEACHATES

Sample designation*	Untreated soil mg/kg	Untreated soil leachate µg/L	Treated soil mg/kg	Treated soil leachate µg/L
B-6				
Chromium	400	10	50	40
Copper	910	240	39	60
Lead	2,500	200	140	70
Zinc	1,000	2,200	50	40
Total	4,810	2,650	279	210
B-7				
Chromium	43	10	47	40
Copper	70	20	12	50
Lead	310	<50	55	<50
Zinc	240	290	80	30
Total	663	320	194	120
B-8				
Chromium	84	10	46	30
Copper	59	20	6	40
Lead	280	100	11	<50
Zinc	190	300	17	100
Total	613	430	80	170

* Depth of samples are B-6 at 1-2 ft; B-7 at 7-8 ft; B-8 at 11-12 ft.

TABLE 14. MATERIAL BALANCE

Date, 1988	Number of columns	Sector	Additive slurry lb	Dry additive lb	Supple-mental water lb	Sodium Sili-cate lb	Total addition lb	Total column soil(a) lb
4/11	7	B	29,720	18,575	4,621	257	34,598	85,027
4/12	17	B	55,407	31,660	10,408	577	66,392	206,499
4/13	12	B	27,622	15,783	6,978	321	34,921	145,764
4/14	9	C	24,138	13,792	5,315	326	29,779	84,908
4/15	18	C	48,603	27,772	4,077	643	53,323	169,816
4/16	9	C	25,823	14,755	708	319	26,850	84,906
	Totals		211,313	122,337	32,107	2,443	245,863	776,920

Material Balance (continued)

Date 1988	Number of columns	Sector	Dry soil(b) lb	Total soil additions(b) lb	Soil weight increase %	Additive addition, HWT-20 dry/ soil dry
4/11	7	B	75,008	119,625	40.7	0.248
4/12	17	B	182,158	272,891	32.2	0.174
4/13	12	B	128,582	180,685	26.1	0.123
4/14	9	C	72,849	114,687	35.1	0.189
4/15	18	C	145,198	223,139	31.4	0.191
4/16	9	C	72,849	111,756	31.6	0.203
	Totals		677,144	1,022,783	31.65	0.181

(a) Average bulk density of untreated soil, based on laboratory results, is 96 lb/ft^3. In Sector B, column depth was 17.9 ft, and in Sector C, 13.9 ft.

(b) Correction from wet soil to dry soil is based on the results; average moisture in Sector B is 11.8% by wt. and in Sector C is 14.2% by wt.

SECTION 9

ECONOMICS

9.1 INTRODUCTION

A cost analysis addresses two main categories: capital costs; and operating and maintenance costs.

Capital costs include both depreciable and nondepreciable cost elements. Depreciable costs include direct costs for site development, capital equipment, and equipment installation; as well as indirect costs for engineering services prior to unit construction (such as feasibility studies and consultant costs), administrative tasks (such as permitting, construction overhead and fee), and contingencies. Nondepreciable costs include startup costs (including operator training, trial or test run expenses) and working capital. Operating and maintenance costs include variable, semivariable, and fixed cost elements. Variable operating cost elements include raw materials, utilities, and residual water disposal costs. Semivariable costs include unit labor and maintenance costs, and laboratory analyses. Fixed costs include depreciation, insurance, and taxes.

The above cost element breakdown, however, is based on a permanently sited hazardous-waste cleanup device. The IWT/Geo-Con system is a transportable unit that will not be installed at a fixed site. Thus, it involves some cost elements that are different in their impact on a cost analysis compared to cost elements occurring with the more typical permanent installations.

In general, the cost for a transportable hazardous-waste remediation-facility falls into three categories: capital costs, including all costs that can be amortized over the service life of the unit; mobilization/demobilization costs associated with startup and shutdown at a given site, and that can be amortized over the duration at the site; and operating costs to operate and maintain the system. Capital costs can be subdivided into direct, indirect, and nondepreciable cost elements. Mobilization/demobilization costs can be accrued as semivariable operating and maintenance costs. Operating costs include variable utility and raw material costs, semivariable labor and maintenance costs, and fixed costs such as depreciation, insurance, and taxes.

Several capital cost elements defined for the permanently sited unit need to be redefined into cost categories pertinent to a mobile unit. These include the direct costs for site development and the direct costs for engineering studies, which on a site-specific basis, become mobilization/demobilization costs. These factors are not included here because of the complexity of the analysis and planning in this area. Total site cleanup is the responsibility of other contractors, with the in situ stabilization/solidification technology used for only a section of the total site remediation.

Based on the above, an overall cost element breakdown, as illustrated in Table 15, can be developed.

9.2 COST ELEMENTS

A detailed discussion of each of the cost elements defined in Table 14 is provided in the following:

9.2.1 Capital Costs

9.2.1.1 Direct Costs--

Equipment fabrication/construction and/or purchase--The current costs for the design, engineering, materials and equipment procurement, fabrication and installation of the in situ stabilization/solidification process, are included as direct costs. The costs include all the subsystems and components installed. Waste preparation equipment is not included as it can be rented or provided by the site-responsible party. Pretreatment or posttreatment of the soil is not required.

9.2.1.2 Indirect Costs--

Administrative/permitting--Administrative costs associated with regulatory compliance issues could be numerous and varied, and these costs are not included in this analysis. The costs that are being accrued under this cost element are directed to the overall non-site-related regulatory activities in establishing federal and state permit requirements, preparing initial permit applications, and supporting permit application information throughout the permit issuance process. Once the final permits are issued, recordkeeping, inspection, survey response to permitting agencies, and additional reporting activities may be required. These costs include the preparation of technical support data, sampling/analysis project plans, and quality assurance project plans by in-house engineering personnel; preparation of RCRA/TSCA permit forms (if applicable); time, travel, and per diem for consultant and in-house staff interfacing with federal EPA officials; and in-house administrative and clerical staff.

For this cost analysis, administration costs, taken as percent of direct costs, include office expenses such as supplies and furniture, but not salaries (included elsewhere).

TABLE 15. COST ELEMENT BREAKDOWN

	Capital cost
Direct	Equipment fabrication/construction or purchase
Indirect	Administrative/permitting contingency
Nondepreciable	Operations procedures/training Initial startup/shakedown Working capital
	Operating and maintenance costs
Variable	Raw materials: HWT-20, sodium silicate Power Water Fuel Waste disposal
Semivariable	Labor Maintenance Analyses Mobilization/demobilization - Site preparation/logistics - Transportation/setup - Onsite checkout - Working capital - Decontamination/demobilization
Fixed	Depreciation Insurance Taxes

Contingency--A contingency cost, approximately 10% of direct capital cost, is usually allowed for unforeseen or poorly defined cost definitions.

9.2.1.3 Nondepreciable Costs--

Operations procedures/training--In order to ensure the safe, economical, and efficient operation of the unit, the creation of operating procedures and a program to train operators is necessary. Costs that may accrue include: preparation of a unit health/safety and operating manual, development and implementation of an operator training program, equipment decontamination procedures, and reporting procedures. All documentation must be site-specific, though they can be derived from standard documents. The preparation costs can be amortized over the life of the equipment.

Initial startup/shakedown--After the unit is brought to a site, it must initially be started and operated to check out the mechanical and technical integrity of the equipment and its controls. This cost is assumed to be one week of labor expenses.

Working capital--Although the unit is a transportable system, it will require a supply of maintenance materials attributable to a nondepreciable capital cost. Maintenance materials typically account for approximately one-half of the total maintenance cost, and three-month inventories are usually maintained. This cost is included in the Geo-Con equipment costs and facility modifications.

9.2.2 Operating and Maintenance Costs

9.2.2.1 Variable Costs--

Variable operating cost elements for this unit include fuel, power, water, chemicals, and process waste disposal. They are defined as variable operating cost elements because they can usually be expressed in terms of dollars-per-unit flow of soil treated and, as such, these costs are more or less proportional to overall facility utilization during specific site operations. It is also assumed for the tabulation of costs that there are no process waste by-products.

Fuel--The fuel requirement for the unit includes diesel fuel to power the crane and hydraulic power pack. In addition, fuel is used for supporting vehicles--backhoe, front-end loader--and for diesel generators for lights and possibly heat.

Power--The power requirement for the unit includes the electrical requirements for the trailers, sampling equipment, auxiliary lighting, etc. This is assumed to come from plant facilities.

Water--Water use is based upon the water content of the feedstock, to bring the cement-like final slurry to about 18% by wt. water. In addition, 500 gal of water is used for decontamination.

Chemicals--The IWT proprietary additive is HWT-20. It is used at a rate of 15 wt% to dry contaminated soil.

Decontamination water--If the unit is not operated 24 h/d, it needs to be cleaned with high-pressure water or steam to prevent plugging. Costs will accrue for the containment and disposal of this waste stream. It is assumed that all decontamination water is used on site.

9.2.2.2 Semivariable Costs

Labor--This analysis determines total operating personnel based upon 1 shift per day, 5 shifts per week for a total of 8 people. This includes 5 process operators, 1 supervisor, a site safety and health officer, and 1 overall coordinator.

In addition, there are 3 support personnel for office operations, including a combined office manager-purchasing agent, a secretary, and a part-time sample technician. This totals 11 people.

Maintenance--Maintenance materials and labor costs are extremely difficult to estimate and cannot be predicted as functions of a few simple waste and facility design characteristics, because a myriad of site-specific factors can dramatically affect maintenance requirements. Annual maintenance cost will be assumed as 10% of capital cost.

Analyses--In order to ensure that the unit is operating efficiently and meeting environmental standards, a program for continuously analyzing waste feed and treated solids is required. Initially sample sets will be taken every day, and less often as operation efficiency improves. A sample set is assumed to cost $1,200.

Mobilization/demobilization--As discussed in Section 8.1, the following costs will accrue to the Geo-Con unit at each specific site. The costs are site-specific and may vary widely, depending on the nature and location of the site. They include site preparation/logistics, transportation/setup, construction supervision, onsite checkout, site-specific permitting/ engineering services, working capital, and decontamination/ demobilization. Notes to Table 16 indicate the items included in the cost analysis.

Site preparation/logistics--The costs associated with site preparation/logistics include advanced planning and management, detailed site design and development, auxiliary and temporary equipment and facilities, water conditioning, emergency and safety equipment, and site staff support. Soil excavation, feedstock preparation, and feed handling costs are also included. This may be performed by companies other than Geo-Con or IWT but still comprises part of the site remediation costs. Due to the temporary and transient nature of the setup at an assumed Florida site, the costs incurred for the demonstration were based in part on Geo-Con estimates. Costs for advanced planning, detailed site design and development, and water conditioning, if needed, are assumed to be part of the site prime contractor's expenses, and are not included.

Transportation/setup--The cost of transportation and setup includes transport to a new location. The costs for the Geo-Con deep-soil-mixing unit are included in mobilization/demobilization and subcontract costs.

Onsite checkout--Once the unit has been set up, it is necessary to shake down the system to ensure that no damage occurred as a result of disassembly, transport, and reassembly.

Working capital--Fuel inventory, sodium silicate, and HWT-20-additive storage facilities will exist at each site and, as such, are semi-variable operating costs specific to the site-specific mobilization/demobilization cost-element breakdown. These storage facilities are included as part of the capital costs.

Decontamination/demobilization--With the completion of activities at a specific site, the unit must be decontaminated and demobilized before being transported to its next location. Costs that will accrue to this cost element include field labor and supervision, decontamination equipment and materials, utilities, security, health/safety activities, and site staff support.

9.3 OVERALL COST EVALUATION

A primary purpose of the economic analysis is to estimate costs for a commercial-size remediation. However, it was assumed for this analysis that part of a large Florida site would be remediated. The costs used were provided by Geo-Con and were based on the unit used during the demonstration. For this case, the analysis assumes that the treatment unit processed sixteen soil columns per day; and that the additive consumption rate was 0.15 lb additive/lb dry soil, based on soil conditions found at the GE site. The results of the analysis are presented in Table 16.

These results show a cost per ton (without fee) for untreated soil of $194 for the 1-auger unit used for the demonstration. As can be seen from the results, 85% of the costs consist of raw materials, equipment rental, and labor.

TABLE 16. ESTIMATED COST

	1-auger assembly
Capital cost	
Direct	
Equipment costs, $	77,000
Indirect, $/ton	
Administration (10% direct costs)	0.45
Contingency (10% direct cost)	0.45
Nondepreciable, $/ton	
Initial startup/shakedown (5 days of labor expenses) and operator training	0.31
Working Capital	--
Operating and maintenance costs	
Variable, $/ton	
HWT-20	52.45
Sodium silicate	0.23
Fuel ($1.00/gal-diesel)	2.16
Electricity ($0.04/kWh)	0.21
Water ($0.80/1,000 gal)	0.02
Semivariable $/ton	
Salaries and living expenses	45.73
Equipment rental and subcontracts	67.90
Consummable	19.29
Analytical services	3.28
Maintenance (10% direct costs)	0.45
Mobilization/demobilization	0.62
Site preparations	--
Misc. (Insurance, taxes, etc.)	0.45
Depreciation	0.45
Totals, $/Ton	194.45

Table 16. Notes

1. The demonstrated Geo-Con unit could process one 3-ft diameter soil column to a depth of 16 ft in 30 min. Thus, 16 columns/d on the average were treated.

2. Operations were based upon 5 d/wk, 8 h/d.

3. Equipment life estimated at 10 yr.

4. It is assumed that 50,000 ft^2 of soil were processed to a depth of 16 ft; this is equivalent to 38,400 ton.

5. Labor and living expenses for Geo-Con operating supervisory personnel were provided by Geo-Con at \$20 yd^3. Support personnel costs were estimated by EPA.

6. Utilities consumption estimates:
   Electricity - provided by others at battery limits at \$0.04/kWh
   Water - the daily average rate for the process, decontaminating, and miscellaneous was 4.3 gpm.
   Diesel Fuel - 140 gal/d

7. Average bulk density of soil is 96 lb/ft^3, or 2,592 lb/yd^3.

8. Chemical consumption:
   HWT-20 - 0.15 lb/lb of dry soil; soil moisture content 8% by wt.; delivered cost \$380/ton.
   Sodium silicate - (41° Baume); 5% by wt. (100% basis) of HWT-20 additive; delivered cost \$177/ton of solution.

9. Labor estimate: 1 shift, 5 days per week; includes overhead (no profit). Data provided by Geo-Con - \$50/yd for 1-shaft augers. Includes all living and travel expenses for 8 people. Since the onsite time is about 2 1/2 yr, assume an office manager and a secretary. In addition, a sampling technician is required. Salaries plus overhead for the non-operating personnel are \$30/h for office manager, \$16/h for a secretary, and \$25/h for a sampling technician.

10. Mobilization/demobilization: Labor, subcontracts, etc. - One week of labor charges for each is assumed.

11. Capital cost of equipment as provided by Geo-Con:
    Mixing plant - \$50,000
    Flow control system - \$20,000 (1-auger)
    Augers & auxiliaries - \$7,000 (1-auger--some added equipment assumed to be rented)

Table 16. Notes (continued)

Totals for 1-auger system, $77,000.

12. Laboratory analysis: First 2 weeks, 1 set of samples daily; then 1 sample set weekly for remainder of the remediation. Sample set cost is $1,200.

13. Rental equipment: Crane, backhoe, hydraulic power pack, pickup truck, other vehicles, miscellaneous. One-shaft auger, $\$70/\text{yd}^3$. Basic data were provided by Geo-Con with some adjustments assumed.

14. Subcontract expenses: Trucking, electric wiring, piping is $\$18/\text{yd}^3$. Data provided by Geo-Con.

15. Miscellaneous: Purchases, insurance, health and safety supplies. Geo-Con estimated cost of $\$25/\text{yd}^3$.

16. Cost for permitting, recordkeeping, inspection, and other related activities were not included in this analysis. Site preparation, since it would be so interrelated with the overall planning and costs of the prime contractor for the entire site, was not included.

17. The maintenance and working capital costs were prorated to the actual time on site, 28 mo for a 1-auger system.

18. Administration and contingency are assumed at 10% of capital cost (per annum) and prorated to the actual time on site.

19. Operator training assumes 5 days of training for Geo-Con operators, the Health and Safety Officer, and sample technician.

20. Many of the costs shown were provided by Geo-Con, and included a fee. Some adjustments were estimated, so that the bottom line in Table 16 more closely estimated an actual cost without fee.

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